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Attached you will find a report on the Concrete Pavement Curing Water Boyer to Water Crossing - Stanislaus County, Contract 51030, which I am forwarding to you for your information and files.

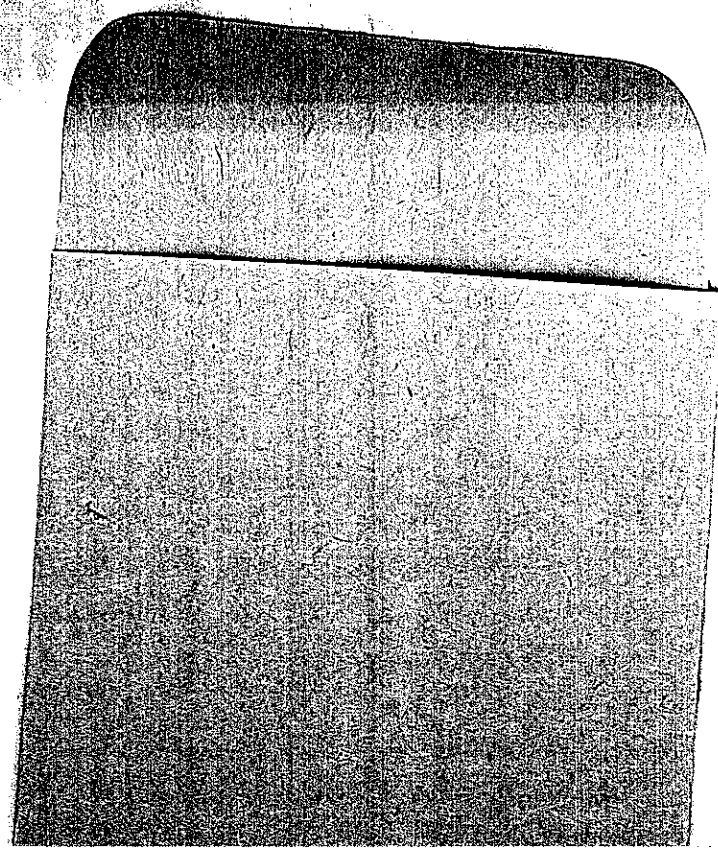
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May, 1951

10 YEAR REPORT
ON THE
CONCRETE PAVEMENT CURING TESTS

Keyes to Hatch Crossing - Stanislaus County
Contract 210TC9 - FAP-171-B,G X-Sta-4-A,Cbr.,B

Constructed in 1941

Report by Thos. E. Stanton, Materials and Research Engineer

SUMMARY

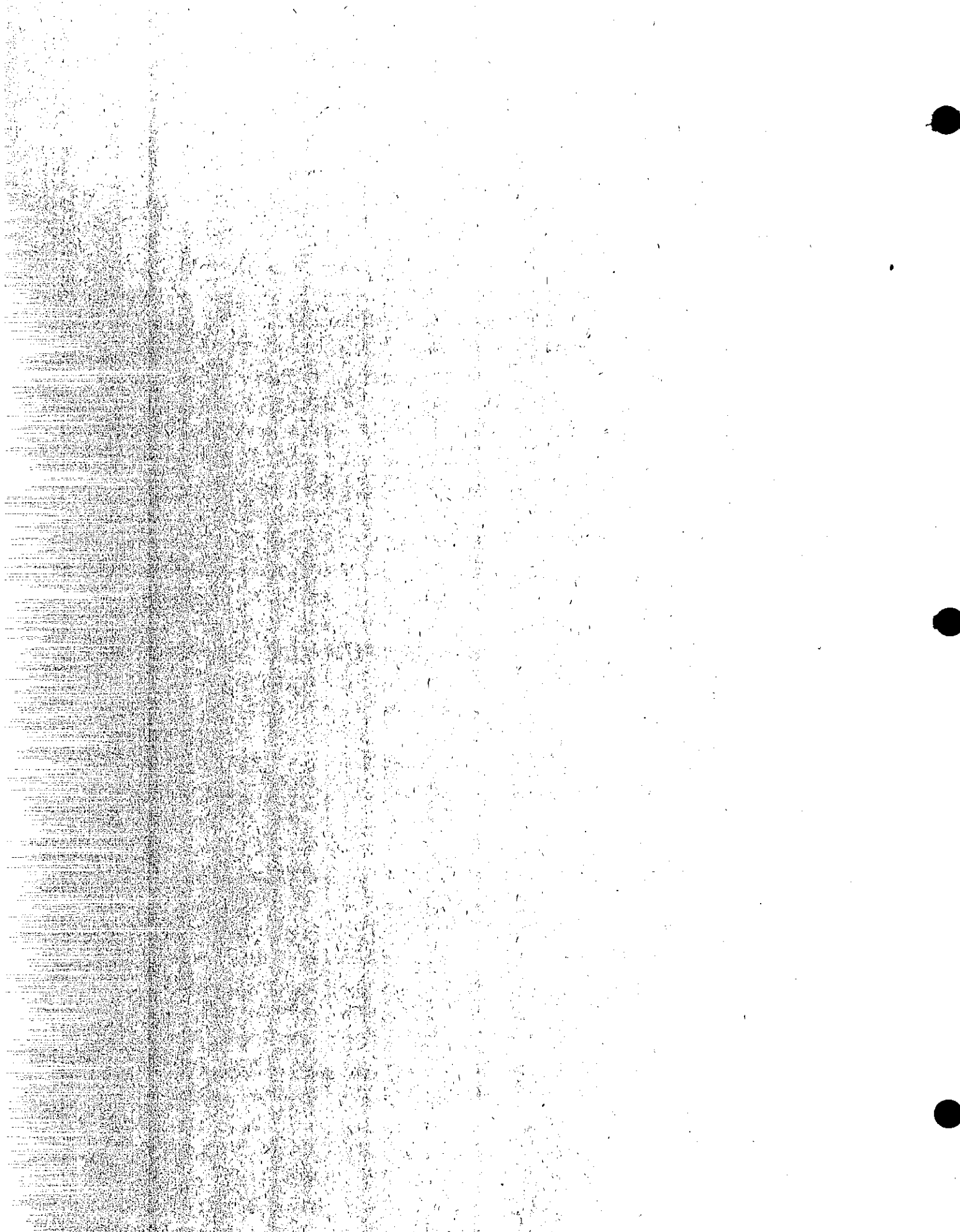
The 1940 Standard Specifications required an 8 day water, cotton mat or impervious paper cure of a Portland cement concrete pavement or permitted the use of a colorless impervious membrane.

The 1945 Standards contained the same provisions in so far as water, paper and colorless impervious membrane curing was concerned but shortened the period of coverage with cotton mats to 72 hours.

By 1949 the Standards were changed to require only 72 hour cure whether by water, cotton mats or paper with the further requirement for light colored pigmented solution when an impervious membrane is used.

The above changes in specifications were at least partially influenced by studies conducted by this Department first about fifteen years ago on the use of cotton mats and second on tests started in 1941 in which were included some nine curing procedures.

Ten years having elapsed since the 1941 curing test series, a condition survey as of the ten year period was made during April of this year (1951), the results of which are herein reported.



As recited in the caption the test was conducted on a section of concrete pavement under construction in 1941 south of Modesto in Stanislaus County, more specifically described as from Keyes to Hatch Crossing, X-Sta-4-A, Cer., B - FAP-171-B,G, Contract 210TC9.

The portion of the contract selected for the curing tests was between Sta. 472+52 and 520+22.

The project was fully reported under date of February, 1942 therefore only those portions of the 1942 report which are essential to a clear understanding of this ten year report are repeated herein.

LOCATION AND CURING METHODS

One mile of the north bound passing lane of the pavement on this section, which aggregated 5.5 miles in length, was selected for the test of nine curing methods as follows:

1. Earth and water 8 Days
2. Earth and Water 3 Days
3. Water only 1 Day
4. Water for 24 hours followed by emulsion clear cure
5. Water for 24 hours followed by Hunt clear cure
6. Emulsion clear cure applied immediately after bump cutting
7. Hunt clear cure applied immediately after bump cutting
8. Sisalkraft paper applied immediately after bump cutting and removed after three days.
9. Cotton mats applied immediately after bump cutting, kept constantly wet for three days and then removed.

Each method of cure was repeated three consecutive days, shifting the order of construction each day as shown in Table I, which likewise shows the location of each section, length and day laid.

TEMPERATURE AND HUMIDITY CONDITIONS

The concrete was placed during July 8, 9, and 10. It happened that the warmest period of 1941 occurred during the laying of this concrete and during the next two weeks, or well past even the 8 day earth and water curing period.

The maximum and minimum air temperatures and humidities during this period were as follows:

	AIR TEMPERATURE		RELATIVE HUMIDITY	
	Maximum	Minimum	Minimum	Maximum
July 8)	106°	--	23	--
July 9) Pouring period	104	63°	22	71
July 10)	102	62	22	61
July 11	100	60	28	80
12	99	57	29	67
13	96	57	34	71
14	99	57	33	80
15	100	59	33	80
16	103	58	27	76
17	105	63	26	73
18	101	62	29	71
19	101	61	31	76
20	104	62	31	69
21	108	65	26	73
22	109	67	28	77
Ave.	102°	61°	28	73

CONCRETE DESIGN

The concrete was a standard five sack mix. Calaveras cement and aggregates from the Hughson Pit in Stanislaus County were used throughout.

An effort was made to maintain a constant water cement ratio of 0.80 by volume and a slump of approximately 2 inches.

CONCRETE TEMPERATURE

To aid in the study of curling tendencies as influenced by hydration temperatures and variations in atmospheric temperature under the different curing methods, two Weston Dial type thermometers were installed in each test section, one to measure the temperature of the top 2" of the pavement slab and the other the concrete temperature at the base, five to six inches below the surface.

In general it can be stated that the highest average maximum and minimum temperatures were encountered with the clear cure. This can be at least partly attributed to the relatively darker color of the surface of the pavement resulting from the coloring pigment in the wax residue from the membrane curing solution. Subsequent similar temperature recordings when a light gray pigmented seal was used were substantially lower than with the darker membrane.

Temperature measurements after the normal curing period compared with the surface color of the pavement, indicated that the temperatures for all sections were materially influenced by the color. Darker shades absorb heat from the sun, thereby building up temperature. It is very probable that after a pavement surface becomes

discolored by oil drippings from motor vehicles there is ultimately no difference in the temperature pattern, regardless of method of cure, except possibly the bituminous membrane cure, until after the membrane is worn off.

Concrete temperatures during the curing period are vitally affected by the method of cure as illustrated in Figs. 2 and 3 of the original (1942) report.

During water cure evaporation helps to hold the maximum temperatures down and thereby narrows the range between maximum and minimum. On the other hand, sealing the surface or otherwise preventing evaporation loss tends to build up early temperature.

PAVEMENT CONDITION AT END OF TEN YEARS

The ten year inspection did not disclose any observable difference in the condition of any of the sections, regardless of method of cure; even the section water cured for 24 hours with no subsequent treatment.

There were a total of approximately 318 fifteen foot slabs between the limits of the test. After ten years only 3 of the 318 slabs show any cracks intermediate between the weakened planes. One crack was obviously caused by a subgrade settlement and the other two were corner cracks close to weakened planes which had not opened up opposite the cracks, thereby indicating a carryover in stress sufficient to rupture the concrete outside the weakened plane.

In 1945 it was noted that at least 36 or over 10% of the slabs in the adjoining 8 day water cure lane between the limits

of the test section had developed transverse cracks.

The attached tabulation shows the location of the cracks noticed in 1945 in the east lane. No additional cracks were counted in the 1951 survey.

Undoubtedly the more extensive cracking in the east lane is due to the nature and volume of the traffic, as this is the main travelled lane. Unfortunately the section selected for the test was the west or passing lane and the test therefore is deficient in that it does not include all of the desirable test conditions in so far as traffic volume is concerned.

The west lane was selected for the reason that it was desired to conduct the test on a continuous stretch of pavement during the warmest summer weather prevailing during the construction of this project. The test was therefore delayed as long as possible and was carried out during the second week in July (July 8th, 9th and 10th, 1941), when the atmospheric temperature ranged from 100° to 104° with a minimum maximum atmospheric temperature of 98° and a maximum of 107° during the two weeks immediately following the first day of the test.

Referring to Column 9 of Table 3 it will be noted that the average compressive strengths of the cores was 7710 p.s.i. at ten years as compared with 5190 p.s.i. at 29 days or an increase of nearly 50%.

There were no marked differences in the strengths of the cores from any of the sections, which might be attributed to

difference in curing procedure. The cores from even the 24 hour cure sections were above the minimum and close to the average.

It would, therefore, appear that our present requirement of a 72 hour water, paper, or cotton mat cure or an approved impervious membrane is adequate for California climatic conditions.

TABLE I.
CONCRETE CURING TESTS
LOCATION AND LENGTH OF TEST SECTIONS AS CONSTRUCTED
X-Stan-4-A, Cer., B Contract 210TC9 Keyes to Hatch Crossing

Concrete Placed 7-8-41			Concrete Placed 7-9-41			Concrete Placed 7-10-41		
1-1	Earth-Water 8 Days	520+22 120'	4-2	Water for 24 Hrs. fol- lowed by emulsion clear cure	504+62 240'	7-3	Hunt Clear Cure applied immediately after bump cutting	488+27 285'
2-1	Earth Water 72 Hrs.	519+02 120'				8-3	Sisalkraft Paper 72 Hrs.	485+42 240'
3-1	Water 24 Hrs.	517+82 120'	5-2	Water for 24 Hrs. followed by Hunt Clear Cure	502+22 240'	9-3	Cotton Mats 72 Hrs.	483+02 240'
4-1	Water for 24 Hrs. followed by emulsion clear cure	516+62 240'	6-2	Emulsion Clear Cure Applied im- mediately after bump cutting	499+82 240'	1-3	Earth-Water 8 Days	480+62 120'
5-1	Water for 24 Hrs. fol- lowed by Hunt Clear Cure	514+22 240'	7-2	Hunt Clear Cure applied immediately after bump cutting	497+42 240'	2-3	Earth-Water 72 Hrs.	479+42 120'
6-1	Emulsion Clear Cure applied im- mediately after bump cutting	511+82 240'	8-2	Sisalkraft Paper 72 Hrs.	495+02 120'	3-3	Water 24 Hrs.	478+22 120'
			9-2	Cotton Mats 72 Hrs.	498+82 120'	6-3	Emulsion Clear Cure applied im- mediately after bump cutting	477+02 120'
7-1	Hunt Clear Cure applied immediately after bump cutting	509+42 240'	1-2	Earth Water 8 Days	492+62 120'	5-3	Water for 24 Hrs. fol- lowed by Hunt Clear Cure	475+82 120'
8-1	Sisalkraft paper 72 Hrs.	507+02 120'	2-2	Earth- Water 72 Hrs.	491+42 120'	4-3	Water for 24 Hrs. fol- lowed by emulsion clear cure	474+62 210'
9-1	Cotton Mats 72 Hrs.	505+82 120'	3-2	Water 24 Hrs.	490+22 195'			472+52
		504+62			488+27			
Total Length 1560 Ft.			Total Length 1635 Ft.			Total Length 1573 Ft.		

TABLE 2. AVERAGE CONCRETE TEMPERATURES, KEYES TO HATCH CROSSING
PAVEMENT CURING TEST, X-Stan-4-A,B. July, 1941.

Sec. No.	Curing Method	AVERAGE CONCRETE TEMPERATURES JULY 8TH TO 22ND, 1941											
		During Curing Period						After Curing Period					
		Ave. Max. Tem.			Ave. Min. Tem.			Ave. Max. Tem.			Ave. Min. Tem.		
		Top	Bot.	Dif.	Top	Bot.	Dif.	Top	Bot.	Dif.	Top	Bot.	Dif.
1	8 Day Earth & Water	90	88	2	66	70	4	107	100	7	74	78	4
2	3 Day Earth & Water	92	90	2	67	71	4	109	102	7	77	81	4
3	1 Day Water	100	100	0	69	74	5	114	107	7	74	82	8
4	24 Hr. Water then emul-sion clear cure	95	96	1	67	73	6	111	105	6	75	80	5
5	24 Hr. Water then Hunt Clear Cure	96	96	0	67	74	7	118	111	7	77	83	6
6*	Emul. Clear cure appld. immediately after bump cutting	110	103	7	76	80	4	110	103	7	76	80	4
7*	Hunt clear cure appld. immediately after bump cutting	120	114	6	78	85	7	120	114	6	78	85	7
8	Sisalkraft Paper	105	102	3	81	85	4	114	108	6	77	81	4
9	Cotton Mats	88	86	2	72	77	5	114	106	8	74	79	5
Average Difference				2*			5			7			5

*On Sections "6" and "7" the clear curing solutions were applied immediately after bump cutting. Due to the at least partial stoppage of evaporation through the wax type membrane, the concrete temperatures rose immediately to a degree depending on the time of day and air temperature at time of application. The same set of temperature is therefore recorded in both the "During Curing" and "After Curing" columns because of the same surface protection and consequent similar temperature pattern throughout the entire period. To a certain extent the same remarks apply to Sections 4 and 5 after the first 24 hours, but in the case of 4 and 5 the division has been made at 24 hours in order to show the difference in maximum temperatures before and after applying the membrane curing solutions.

TABLE 3. SUMMARY OF CONCRETE TESTS - Concrete Pavement Curing Tests
 Keyes to Hatch Crossing - Stanislaus County
 Contract 210TC9 - FAP-171-B,G. X-Sta-4-A, Cer., B.
 Test Sections Placed July 8, 9, and 10, 1941

1	2	3	4	5	6	7	8	9	10
Test Sec. No.	Curing Method	Mod. of Rup.		Compressive Strength					Surface Hardness
		29 Da.	90 Da.	Cyls.	Beam Ends		Cores		Depth of Groove
					29 Days	90 Days	29 Days	10 Years	
1	8 Day water cure	700	757	4040	5360	5700	5300	7780	0.124"
2	72 Hr. Water Cure	660	666	4210	5200	5660	5360	7915	0.135"
3	24 Hr. Water Cure	508	520	4100	4720	4850	5000	7430	0.144"
4	Emul. after 24 Hrs.	592	665	4250	5160	5600	5260	7855	0.104"
5	Hunt " " "	618	686	4460	5290	5670	5390	8085	0.084"
6	Emul. appld. same day	549	603	4210	4590	5100	5180	8195	0.120"
7	Hunt " " "	537	585	3910	4610	5130	5060	7550	0.095"
8	Kraft Paper-72 Hrs.	618	675	4150	5190	5660	5150	6840	0.117"
9	Cotton Mats- 72 Hrs.	611	709	4030	5220	5800	5010	7745	0.106"
Average		599	652	4151	5038	5463	5190	7710	0.114"

1. First tests at 29 days instead of customary 28 days controlled by field and laboratory conditions.
2. All field control cylinder specimens cured in water at laboratory, hence the differences in test results are due to differences in concrete mix and fabrication and not to curing procedure.
3. Test figures on the concrete represent the average of tests on 3 to 12 specimens in each set except surface hardness, for which only three tests were made for each method of cure.

TABLE 4. TABULATION OF CRACKS IN SLABS OF THE EAST LANE OF THE CONCRETE PAVEMENT BETWEEN KEYES AND HATCH CROSSING, BETWEEN STATION 472+52 and STATION 520+22, X-Sta-4-A, Cer., B, CONTRACT 210TC9, FROM NOTES BY T. E. STANTON, JUNE 22, 1945.

W. Lane Test Sections		Length	Number of Cracks in 15 Ft. Slabs East Lane 6-22-45
4-3	Sta. 472+52 - 474+62	120'	1
5-3	474+62 - 475+82	120'	5
6-3	475+82 - 477+02	120'	5
3-3	477+02 - 478+22	120'	4
2-3	478+22 - 479+42	120'	4
1-3	479+42 - 480+62	120'	0
9-3	480+62 - 483+02	240'	0
8-3	483+02 - 485+42	240'	0
7-3	485+42 - 488+27	285'	2
3-2	488+27 - 490+22	195'	4
2-2	490+22 - 491+42	120'	2
1-2	491+42 - 492+62	120'	1
9-2	492+62 - 493+82	120'	0
8-2	493+82 - 495+02	120'	0
7-2	495+02 - 497+42	240'	2
6-2	497+42 - 499+82	240'	0
5-2	499+82 - 502+22	240'	0
4-2	502+22 - 504+62	240'	0
9-1	504+62 - 505+82	120'	1
8-1	505+82 - 507+02	120'	0
7-1	507+02 - 509+42	240'	0
6-1	509+42 - 511+82	240'	0
5-1	511+82 - 514+22	240'	0
4-1	514+22 - 516+62	240'	2
3-1	516+62 - 517+82	120'	1
2-1	517+82 - 519+02	120'	2
1-1	519+02 - 520+22	120'	0
		4770'	36

Note frequency between stations 474+62 and 479+42; also between Stations 485+42 and 491+42.

Foundation and subgrade may have had bearing.

Mr. Walsh

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3435 Serra Way
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January 30, 1951

INTRA-DISTRICT AND DEPARTMENTAL CORRESPONDENCE

TO: All District Engineers
and All Headquarters Heads
of Departments.

FROM: T. E. Stanton
Materials & Research Dept.

Enclosed you will find copy of the Preliminary
Report on the Fairfield Test Highway which I presented
at the recent Highway Research Board Meeting in
Washington, D.C.

T. E. Stanton

T. E. Stanton
Materials and Research Engineer

TES:RB
Encl.

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January, 1951

REPORTS ON EXPERIMENTS WITH CONTINUOUS REINFORCEMENT IN
CONCRETE PAVEMENTS - CALIFORNIA

Thos. E. Stanton, Materials and Research Engineer
California Division of Highways

SYNOPSIS

In the fall of 1938 the Public Roads Administration and the Indiana State Highway Commission initiated the construction of a number of experimental sections of reinforced concrete pavement⁽¹⁾.

Supplementing the Indiana studies, in the fall of 1947 the Illinois Division of Highways and the New Jersey State Highway Department undertook similar constructions⁽²⁾ and during 1949 at the instigation of the U. S. Bureau of Public Roads the California Division of Highways constructed a one-mile section of continuously reinforced concrete pavement in Solano County in the vicinity of the town of Fairfield.

Eastern State projects contain a number of test sections with variable size, spacing and position of the steel. For various reasons, which it is not necessary to review in this report, it was decided to confine the California project to the limited number of variables herein recited. There is, therefore, no opportunity to compare directly with the three earlier projects described in Proceedings of the Highway Research Board except where the conditions are reasonably similar.

(1) Reported in the Proceedings of the Highway Research Board December 1939, Page 193. 10 Year Performance Report 1949, Page 45.

(2) Reported in the Proceedings of the Highway Research Board, December, 1949, Page 33.

The California project was designed primarily to study the stresses in the steel reinforcing and the crack incidence in an 8" uniform thickness continuously reinforced pavement slab, with the steel centrally placed in the depth of the slab, as well as long time performance with relation to riding qualities.

General Description

The project is part of U. S. Route 40 connecting the metropolitan areas of the San Francisco Bay Region and Sacramento. The test section was constructed as part of a contract in Solano County between LedgeWood Creek and 3.5 miles east of Fairfield.

Fig. 1 shows a general layout of the project. Fig. 2 shows information regarding grades, location of test section, dates pavement was constructed, etc.

The project in general consists of a four-lane divided highway over new alignment. Each side of the divided highway consists of two 12 ft. wide contiguous lanes of 8 in. thick Portland cement concrete. The contiguous lanes are tied together with 5/8 in. diameter 30 in. long tie bolts on 30 in. centers. There is a tongue and groove joint at the junction of the two lanes.

The territory traversed is generally flat valley land used for grazing. The native soil along the project is of adobe of somewhat variable composition, having a California Bearing Ratio ranging from 2% to 20% and expansions ranging from 1.7% to 10.8% and Atterberg limits of L.L. 36 to 43 and P.I. 16 to 23. A ten inch layer of gray volcanic ash (Tuff) was placed as imported borrow over the adobe. The Tuff has an average compacted weight

of 65 lbs. per cubic foot at 25% to 30% optimum moisture and a California Bearing Ratio ranging from 150% to 200%. As the Tuff had little cementing value the upper 4 in. of this subgrade material was treated with 3.5% of cement by weight of dry material to avoid washing, shifting, pumping, and step-offs.

The imported base material was specified for the project as a whole, including the reinforced test section.

The pavement concrete was Class B (5 sack) with 2-1/2 in. maximum size coarse aggregate. Outside of the mile long reinforced section, weakened plane joints were placed at 15 ft. intervals with no expansion joints except at each end of the continuously reinforced test section. The surface of the newly laid pavement was kept moist by applying water with a fog nozzle until the application of a light gray pigmented curing compound.

Traffic

The average daily traffic over this road amounts to approximately 12,000 vehicles of all types. Therefore, the traffic on the test section over which only the west bound traffic passes is approximately one-half this amount or an average of 6,000 per day.

Description of Test Section

The one mile of continuously reinforced test section with 4 in. unrestrained expansion joints at each end was constructed in the two contiguous west-bound lanes. The longitudinal reinforcement consisted of 1/2 in. old type deformed steel bars on 4 in.

and 5 in. centers placed at the center of the slab. Transverse 1/2 in. steel bars were placed on 5 ft. centers. No weakened plane joints were placed in the reinforced section except as noted in the portions in which stress measuring SR-4 gages had been installed.

One grade of steel was specified but two grades were used owing to the fact that the contractors purchased the steel from two vendors and one vendor had, through a misunderstanding, rolled a harder grade than the other (Fig. 3).

Advantage was taken of this happenstance to use one grade for one half of the mile long test section and the other grade in the other half, the reinforcement being continuous throughout.

The lower strength bars were spaced 4 in. c/c and the higher strength 5 in. centers.

The amount of 1/2 in. reinforcing for one 12 ft. lane per mile and average characteristics of the steel were as follows:

Section	Spacing	% Steel	Tons Steel Per Mile	A V E R A G E	
				Elastic Limit	Ultimate Strength
1	4"	0.62	71.4	54,090 p.s.i.	84,120 p.s.i.
2	5"	0.5	58.3	71,935	121,250

The reinforcing steel was furnished to the job in 30 ft. lengths. All splices were staggered and lapped 40 diameters or 20 in. for the 1/2 in. steel. The longitudinal reinforcing steel was carried continuously through all construction joints and through the transition between Sections #1 and #2, (Fig. 4).

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Test Units

A. Longitudinal Movement

Reference points for measuring the overall longitudinal movement of the pavement on the subgrade were installed in both lanes at the beginning and end of the test section. Additional units were installed in the traffic lane in both the standard concrete and the reinforced concrete at 100,200,300,400,600 and 800 ft. from each end of the test section. Three additional points were installed, one at the midpoint of the test section and the other two at 100 ft. each side of the midpoint.

The reference points consisted of an open bottom steel box fitted with a weatherproof lid and a reference rod driven 2 feet into the subgrade. Measurements of the longitudinal movement were made with calipers and micrometers with an accuracy of 0.01 in.

Movement up to one year is shown in Fig. 5.

B. Joint and Crack Width Measurements

Brass inserts were placed, in the fresh concrete, across each expansion joint in both the traffic and passing lanes for measuring the opening and closing of the joints. Brass inserts were also placed across the first 14 weakened plane joints, in the traffic lane only, in the standard unreinforced concrete, extending from each end of the test section. Additional brass inserts were placed across a few formed weakened plane joints in the reinforced sections at points where the stress in the reinforcing steel was to be measured. Readings were made with a micrometer to an accuracy of 0.002 in.

At an early age before the formation of the bulk of the intermediate shrinkage cracks, the maximum measured crack opening was 0.04 in. at an interior construction joint. At the weakened planes the maximum at the same age was 0.017 in. The crack widths of all of the early formed cracks decreased with further intermediate cracking, even with a 40° drop in temperature.

Additional brass inserts on 48 in. centers were placed in the traffic lane for the first 100 ft. from the expansion joints in the reinforced steel section to catch and measure changes in width of any naturally occurring transverse cracks. Readings were made with a special micrometer to an accuracy of 0.005 in.

Curing

Curing of the concrete was with a light gray pigmented solution under specifications similar to the Bureau of Reclamation specifications for white pigmented curing solutions, but lightly tinted to reduce potential glare.

Order of Construction

Paving of the left (traffic) lane of the test section was started on May 23, 1949 and finished on May 25, an average run of 1427 feet or 521 cubic yards per day for the 12 ft. wide by 8 in. thick concrete slab.

The specifications required the contractor to start paving each lane of the test section at the beginning of the day and to carry the reinforcing continuously across the transverse construction joint between daily runs. It was required that

pouring the second lane should match the operations on the first lane; namely, to start the second lane in the morning at the same station as the first lane and to quit at the end of the first day in the second lane at the same station as the first day in the first lane. This procedure was followed on both lanes for the first day and the start of the second day.

However, on the second day of the second lane, the speed of the contractor's operations had increased to such an extent that he was able and was permitted to complete the entire mile the second day; the second day's run being 3060 lineal feet of pavement.

The atmospheric and concrete temperatures during the paving operations were moderate to high.

C. Stresses in Reinforcing Steel
Measured with SR-4 Gages

SR-4 gages were installed on selected reinforcing bars at two locations in each section in each lane; a total of eight groups (Figs. 8,9,10 and 11). The arrangement of reinforcing bars and gages was such that part of the gages measured stress in the reinforcing steel at a formed weakened joint and part the stress in the reinforcing steel in uncracked concrete. Natural cracks have formed at some gage locations.

The SR-4 type A-1 gages were attached at the laboratory to 20 ft. lengths of the reinforcing bars; all loose scale and deformations being first removed from the bars to obtain a smooth surface at the location of gage attachment. The surfaces were thoroughly cleaned and gages attached with Cellulose cement.

General Electric Company 16 A.W.G. $3/64$ in. Flamenol insulated wire was soldered to each gage lead. The gages were then waterproofed with 3M EC711 air drying rubber cement, after a minimum of 7 days drying period. The rubber cement waterproofing was applied in 7 to 10 thin coats, allowing a 24 hour drying period between each coat. A final protective coat of 2 layers of $1/2$ lapped 3-M Scotch 33 electrical tape was placed over the gages (Fig. 6).

Each gage was calibrated at the Laboratory after attachment to the bar by stressing the bar by increments to just below the yield point and taking strain readings on the gages at each increment of load.

The temperature compensation units consisted of gages cemented to 4 in. lengths of reinforcing steel with lead wires soldered to the gages and then waterproofed, the assembly then being placed in a 6 in. length of 1 in. steel tube conduit with 2 disks of $1/2$ in. Celotex placed in each end and sealed with Petrolastic. The whole temperature compensating assembly was then wired to the reinforcing steel with the center line of the assembly at the elevation of the reinforcing steel, mid-depth of the pavement (Fig. 6).

Lead wires from all SR-4 gages were brought out to the shoulder and attached to terminal boxes. Readings were taken with a standard Baldwin SR-4 indicator connected to the lead wires.

A total of 186 active SR-4 gages and 72 temperature compensation gages were installed in the test sections.

The insulation resistance of the active gages decreased materially within the first six months and excessively after the first year, but the temperature compensation gages have, in general, shown a high resistance to ground up to 18 months.

The high percentage of temperature compensating gages still showing a high resistance to ground indicates that the method used to protect the lead wires and waterproof the gages was adequate for at least eighteen months when suitable protection is provided. This would indicate that some better method of protection should be provided for protecting the active gages from the action of the concrete.

The insulation resistance to ground at various intervals after installation in the concrete was as follows:

Age After Installa- tion in Concrete Pavement	PERCENTAGE OF SR-4 GAGES WITH INDICATED OR GREATER MEGOHM RESISTANCE TO GROUND							
	ACTIVE GAGES				TEMP. COMP. GAGES			
	MEGOHM RESISTANCE TO GROUND							
	10	25	50	100	10	25	50	100
	PERCENT GAGES WITH MEGOHM RES. INDICATED ABOVE							
3 Days	100	100	100	100	100	100	100	100
6 Months	87	73	40	15	99	99	99	99
12 Months	74	25	4	0	99	99	99	99
18 Months	5	0			99	99	99	99

It will be noted that at the end of 12 months after construction at least 74% of the active gages still measured 10 megohms or greater resistance to ground. The resistance to ground deteriorated until at 18 months only 5% of the active gages measured 10 megohms or greater to ground. The insulation resistance of the temperature compensating gages has remained high, with 99% having a measured resistance of 100 megohms or better to ground at 18 months.

The average measured stress in the reinforcing steel, between cracks, increased steadily (Fig. 7) irrespective of temperature and moisture conditions in the pavement at the time readings were taken. Readings taken at 18 months (not shown on Fig. 7) were exceptionally high.

The average measured stress in the reinforcing steel, across formed cracks, increased with diminishing temperatures to a high at age of 6 months (Fig. 7) and dropped only slightly with a raise in temperature at age of 13 months. Measurements taken at 18 months, not shown on Fig. 7, were beyond any reasonable figure.

74% of the readings made at 18 months exceeded the range of the SR-4 indicator. The calculated stress, based on calibrations made below the elastic limit, was frequently much above the ultimate strength of the reinforcing bars.

At early ages (less than 3 months) the readings on pairs of SR-4 gages opposite each other on the same reinforcing bar (Figs. 8,9,10 and 11) were in agreement within 10%. There was, however, a noticeable increase in the variations in readings at

3 months and at 6 months, many of the pairs of gages varied 100%. This, plus the drop in insulation resistance of the active gages, indicates that stress readings beyond the 3 month period are not reliable and indicate stresses far in excess of those actually developed in the steel.

Now that the active gages are inoperative, it is in order to cut some cores through the steel bars to inspect the condition of the bars at the points of highest indicated stress.

D. Concrete Temperature Measurements

Iron constantan thermocouples were installed; (1) one inch up from the bottom; (2) on the reinforcing steel in the center of the concrete slab, and; (3) one inch down from the top of the pavement slab. This installation was repeated at sufficient gage locations to secure a temperature record of the concrete at the time the concrete was placed. Temperature records have been made each period at which readings have been taken on the SR-4 gages as well as at any other times measurements have been made of the opening and closing of the joints.

Concrete Tests

Numerous test specimens (in the form of cylinders and beams) were cast during the progress of the work for the usual compression and modulus of rupture tests and compressive and dynamic modulus of elasticity.

In addition to the compression and modulus of rupture tests special 6 in. x 10 in. concrete cylinders were tested for tension.

The tension test procedure and test results are hereinafter described. Remarkably consistent tension strength results were secured. The results are deemed of sufficient significance to justify including as a part of this report. Cores were cut and tested at 28 days and one year.

There are some fairly wide differences in the strength of the concrete poured on different days, but more particularly between the two lanes which were constructed fifteen days apart. These differences can be attributed, in part at least, to differences in temperature at time of placing and in part to differences in water cement ratio. At times the construction engineers were concerned about the proper distribution of the concrete through and around the steel reinforcing (maximum size coarse aggregate 2-1/2 in.). The tendency, therefore, was to increase the W/C ratio and consequently the slump to insure what was felt to be a desirable consistency to avoid honeycomb and hang-up on the steel. After observing some honeycomb along the edges of the first constructed lane the water cement ratio was increased slightly during the construction of the second or passing lane.

However, observation of the cores cut from the relatively dry concrete in the first (traffic) lane and from the wetter concrete in the second (passing) lane, as well as of the concrete adjacent to the side headers did not disclose any material deficiency in placement of any of the concrete, regardless of consistency.

Concrete Strength

As will be noted from a study of the compressive, modulus of rupture and tension tests the concrete was of good quality throughout although there is a marked difference in strength between the earlier built traffic lane and the later built passing lane, (Tables 1 and 2).

As previously stated this difference was probably due to the fact that the temperature of air and concrete during the construction of the earlier built traffic lane was greater and the water cement ratio lower than during the construction of the second (passing) lane.

The effects of the lower strengths are not appreciably apparent to date in the pavement performance, the crack incidence being substantially the same in either lane. It would, therefore, appear that differences in strength of the order noted are insufficient to effect any measurable differences in concrete performance, at least up to the period covered by this report (1-1/2 years).

Tension Test Equipment and Procedure

In an effort to determine the tensile strength of the concrete at early ages - 12, 24 and 48 hours - a special type of test specimen and field testing equipment was designed.

The test specimens consisted of 6" x 10" concrete cylinders cast in standard 6" x 12" split steel molds with facilities for accurately placing and aligning two 5/8" carriage type bolts

with specially machined heads abutting at the mid-point in the specimen. Soft rubber tubes were placed over the greater portion of the rods to minimise bond with the surrounding concrete as well as to assist in eliminating any eccentricity in alignment during the application of the load (Fig. 13).

Holes were drilled in the bolt heads for the insertion of a pin to maintain alignment and prevent movement during fabrication.

A special breaking machine was built for the early age field tests (Fig. 14).

Crack Record

Initial shrinkage crack records were made early in the morning following each day's pour. As was anticipated numerous transverse cracks have developed (Figs. 16, 17 and 18). This report includes the crack record up to one year at which time the average number of cracks per 100 ft. of pavement equaled 22 with an average slab length of 4.5 ft. except for the first 140 ft. from each end, where the slab lengths were substantially greater.

As will be noted in the crack record diagrams (Fig. 16) the slab lengths were likewise greater just before the construction joint at the end of each day's pour but quite short at the start of the next day's pour, notwithstanding the continuity of the reinforcing across the construction joint (Figs. 16 and 19).

Roughness Measurements

Initial and subsequent pavement roughness measurements were made with the Hveem Profilometer and by Professor Moyer with equipment developed under his direction at the Institute of Transportation and Traffic Engineering of the University of California, Berkeley. See Fig. 20 for typical profilograph (morning and afternoon) recorded by the Hveem Profilometer.

Comparative Cost Studies

Following is a comparison of the cost per mile of a 12 ft. lane of an unreinforced and a reinforced concrete pavement slab of the thickness and percentages of reinforcement in the Fairfield Test Highway at the project bid prices per cubic yard of concrete (\$14.00) and per pound of steel in place (\$0.08):

1. Unreinforced	\$21,896.00
2. Reinforced with 1/2" bars 4" c (0.62%)	\$33,317.00
3. Reinforced with 1/2" bars 5" c (0.50%)	\$31,227.00

It would, therefore, appear that reinforcement to control cracking is probably not economical and cannot be justified unless an equivalent benefit is attained with relation to long-time riding qualities and greater durability or the slab thickness and the supporting base can be modified sufficiently to offset the added cost of the reinforcing.

In this connection the following comparative cost data is of interest (all figures being based on the unit bid prices for the Fairfield Test Project):

D E S I G N	COST PER MILE OF 12' LANE AT CONTRACT PRICES		
	Concrete Slab	Treated Base	Total
(a) 8" Unreinforced (as constructed)	\$ 21,896	\$ 5,086 ¹	\$ 26,982
(b) 8" Reinforced (0.5% - 5" c/c) (as constructed)	31,227	5,086 ¹	36,313
(c) 8" Reinforced (0.5% - 5" c/c) (No Selec. Mtl. Base)	31,227	0,000	31,227
(d) 6" Reinforced (0.5% - 6.5" c/c) (10" Selec.Mtl.Base(4" Cemt.Tr.)	23,420	5,086 ¹	28,506
(e) 6" Reinforced (0.5% - 6.5" c/c) 4" Sel.Mtl.Cemt.Tr. Base	23,420	2,656 ²	26,077
(f) 6" Reinforced (0.5% - 6.5" c/c) No Selec. Mtl. Base	23,420	0,000	23,420

- (1) 10" Imported Selected Material Base - Top 4" Cement Treated.
- (2) 4" Imported Selected Material Base - All Cement Treated.

From the above tabulation it will be noted that a 6" reinforced concrete base (0.5% Steel - 6.5" c/c) with a 4" Cement Treated Selected Material Base compares in cost with an 8" unreinforced slab with the 10" select material base of which the top 4" was cement treated.

Additional projects designed to compare the performance of the above alternate designs as well as other competitive designs appear in order.



Summary

Owing to the comparatively short period which has elapsed since the construction of the project described in this report there are few conclusions which can be reached with assurance at the present time.

The crack incidence is high in a continuously reinforced slab of the design and length of this project (one mile without substantial expansion or shrinkage relief).

These cracks, although not wide at present may subsequently develop decidedly adverse and objectionable characteristics. In a few cases they have already done so.

To avoid numerous shrinkage cracks it appears necessary to break the continuity of the reinforcing at relatively short intervals - say 100 to 200 ft. This checks with the experience elsewhere.*

Whether or not expansion joints should be provided or weakened planes at the breaks in continuity of reinforcing is not apparent from test data to date, at least under California climatic conditions.

Obviously atmospheric temperature conditions during and immediately following construction is an important factor.

The California project was constructed in the summer and under relatively high atmospheric temperature conditions. Much

*10 Year Progress Report by Cashell and Benham on the Indiana Test Highway, Proceedings, 29th Annual Meeting, Highway Research Board, Vol. 29, 1949.

higher subsequent shrinkage and consequent higher crack incidence could be anticipated than had the construction been carried on during the lower temperature conditions which prevail during the late fall, winter and early spring months.

The effect of time of day and/or order of construction is likewise apparent from the crack development at the construction joints where even though the reinforcing steel is carried continuously across the construction joint the crack incidence is much less at the end of the day's run, just before reaching the construction joint, than during the first hour of the succeeding day when the incidence is somewhat greater than the average.

Up to one and one half years the crack incidence was not materially affected by the percentage of steel, the incidence being substantially the same for the 0.50% - 5" spaced high yield bars as for the 0.62% - 4" spaced standard medium yield bars.

Furthermore, the crack development at 18 months was apparently not appreciably influenced by differences in early concrete strengths of the order observed on the Fairfield project.

Acknowledgements

The author wishes to express appreciation to the staff of the Materials and Research Department for their assistance; particularly to Associate Electrical Engineer J. E. Barton who had charge of the installation of the strain gages and other pavement movement and strain measurement units and the subsequent measurements, recordings and analysis of the strain test data, etc.; also to Associate Materials and Research Engineer L. P. Kovanda who had charge of all work relating to concrete mixture design and concrete tests, including analysis of the concrete test data.

TABLE 1

AVERAGE CONCRETE COMPRESSIVE STRENGTH TESTS

FAIRFIELD TEST HIGHWAY

5-SACK CONCRETE

- (1) 6" x 12" Field Cylinders - Compressive Strength in p.s.i.
(Figures are the average of all cylinders cast each day)

Date Cons.	AVERAGE TEMPERATURE		A G E			
	Conc.	Air	3 Days	10 Days	28 Days	1 Year
TRAFFIC LANE						
5-23-49 AM	85°	96°	----	3240	4330	----
5-24-49 AM	83°	88°	2180	3715	4730	6105
5-25-49 PM	100°	99°	----	3145	4130	----
Ave. Tr. Lane	89°	91°	2180	3367	4397	6105
PASSING LANE						
6-7-49 PM	89°	85°	----	2675	4005	----
6-8-49 AM	80°	71°	1525	2995	4270	5315
Ave. Pass. Lane	85°	78°	1525	2835	4138	5315

- (2) 5" x 6" Beam Ends (Modified Cube)

TRAFFIC LANE						
5-24-49 AM	83°	88°	2850	4330	5515	6310
PASSING LANE						
6-8-49 AM	80°	71°	1980	3325	4720	5820

- (3) Cores from Pavement - Compressive Strength in p.s.i.
(Figures are the average of all cores each day)

TRAFFIC LANE						
5-23-49 AM	85°	96°			5060	6510
5-24-49 AM	83°	88°			4725	6005
5-25-49 PM	100°	99°			4665	6245
Ave. Tr. Lane	89°	91°			4817	6253
PASSING LANE						
6-7-49 PM	89°	85°			3855	4750
6-8-49 AM	80°	71°			3850	5085
Ave. Pass. Lane	85°	78°			3853	4968

TABLE 2

AVERAGE MODULUS OF RUPTURE AND TENSION TESTS

FAIRFIELD TEST HIGHWAY

5-Sack Concrete

(1) Modulus of Rupture - (5" x 6" x 3 1/4" Beams)

Date Cons.	AVERAGE TEMPERATURE		AGE AT TEST			
	Conc.	Air	3 Days	10 Days	28 Days	1 Year
TRAFFIC LANE						
5-24-49	83°	88°	470	625	675	810
PASSING LANE						
6-8-49	80°	71°	355	505	625	685

(2) Tension (6" x 10" Cylinders)

Date Cons	AVERAGE TEMPERATURE		AGE AT TEST					
	Conc.	Air	12 Hrs.	24 Hrs.	48 Hrs.	3 Da.	10 Da.	28 Da.
TRAFFIC LANE								
5-24-49	83°	88°	105	136	184	215	295	327
PASSING LANE								
6-8-49	80°	71°	41	72	123	155	255	284

Beginning of Project
Station 397+88.28

Reinforced Concrete Pavement Test

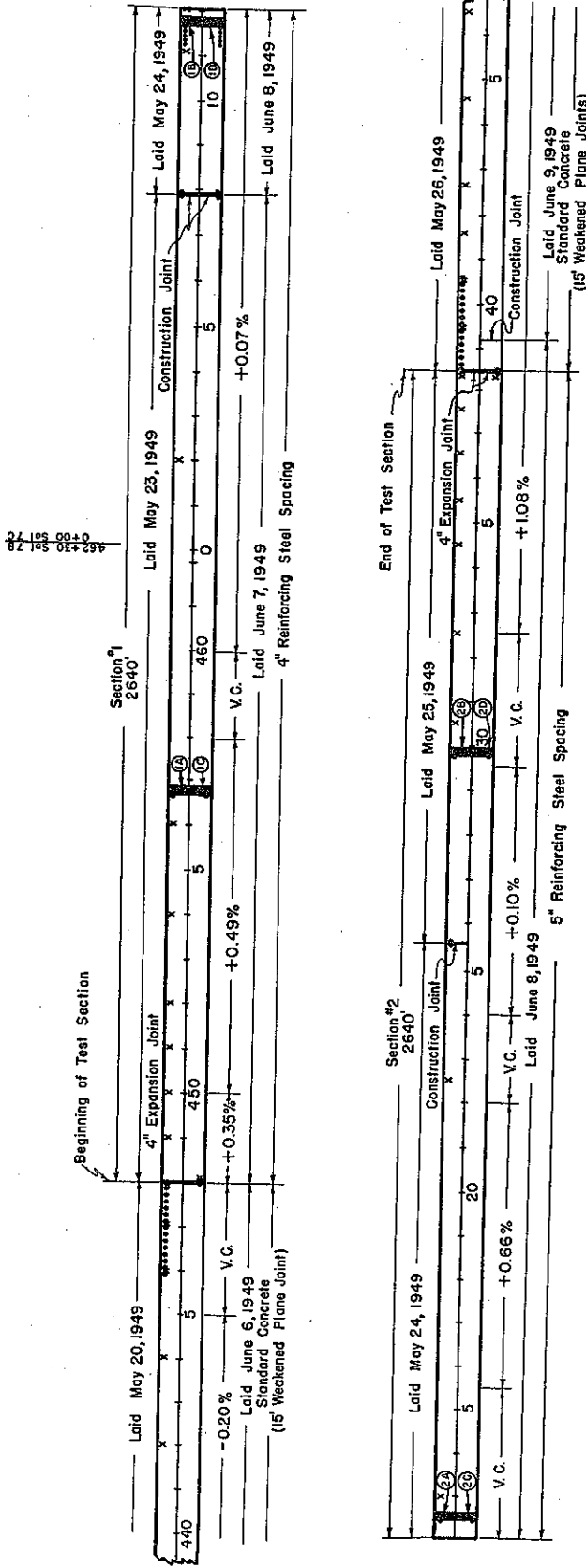
End of Project
Station 200+20.24

Map showing the Sacramento-San Joaquin River Delta region, including Rancho Tolenas, Rancho Potos, Rancho Suisun, and Rancho Rockville. The map details the proposed route for the Sacramento-San Joaquin River Delta Diversion Project, showing the alignment of the project through the delta area. Key locations marked include Sacramento, Yacaville, Potos, Tolenas, Suisun, and Rockville. The map includes a scale bar (0 to 10 miles) and a north arrow.

Fig. 2

PLAN OF FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST

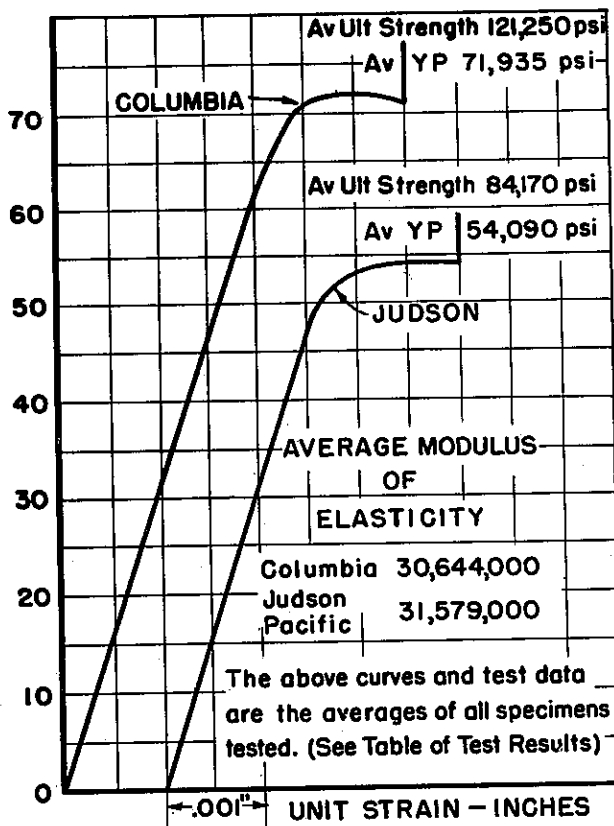
X - Sol-7-B,C



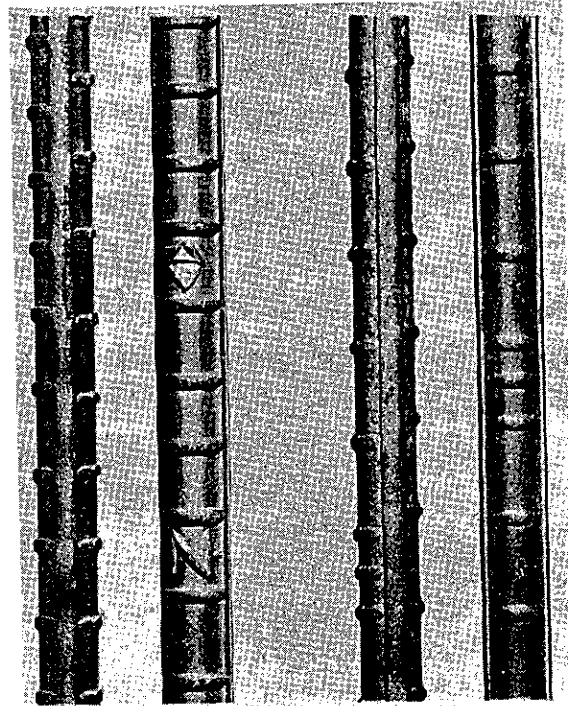
LEGEND

- SR-4 Gage Section See Figs 8, 9, 10, & 11 for detail.
- X Longitudinal Movement Boxes
- Gage Points for Joint Openings

STRESS-STRAIN DIAGRAM



TYPE OF DEFORMATION



COLUMBIA

JUDSON PACIFIC

TEST RESULTS

JUDSON PACIFIC

Heat No	No of Tests	Elongation 8" %	Elastic Limit PSI	Ult. Strength P.S.I.	C	Mn	Phos	Sul
1519	6	16.75	55710	87015	.41	.59	.005	.038
2134	6	17.05	54675	86450	.42	.52	.007	.046
1451	5	16.25	54440	83250	.40	.53	.005	.032
1489	6	19.25	52665	81975	.39	.53	.006	.037
2132	6	17.20	52950	81925	.40	.53	.006	.043
Average		17.30	54090	84120	.40	.54	.006	.039

COLUMBIA

54078	5	11.97	71725	121260	.56	.85	.016	.035
71568	6	11.23	69625	116195	.60	.93	.011	.027
71948	6	12.11	69160	118390	.58	.88	.012	.030
54508	5	10.57	73460	122670	.61	.87	.013	.035
54078	5	10.23	73010	124750	.55	.98	.020	.036
71988	5	11.92	74630	124440	.56	.74	.014	.028
Average		11.67	71935	121250	.58	.88	.014	.033

Fig 3 Characteristics of $\frac{1}{2}$ " Deformed Steel Bars in the Fairfield California Reinforced Concrete Pavement Tests.

HOITAMP-170 TO 171

HOITAMP-170 TO 171

HOITAMP-170 TO 171

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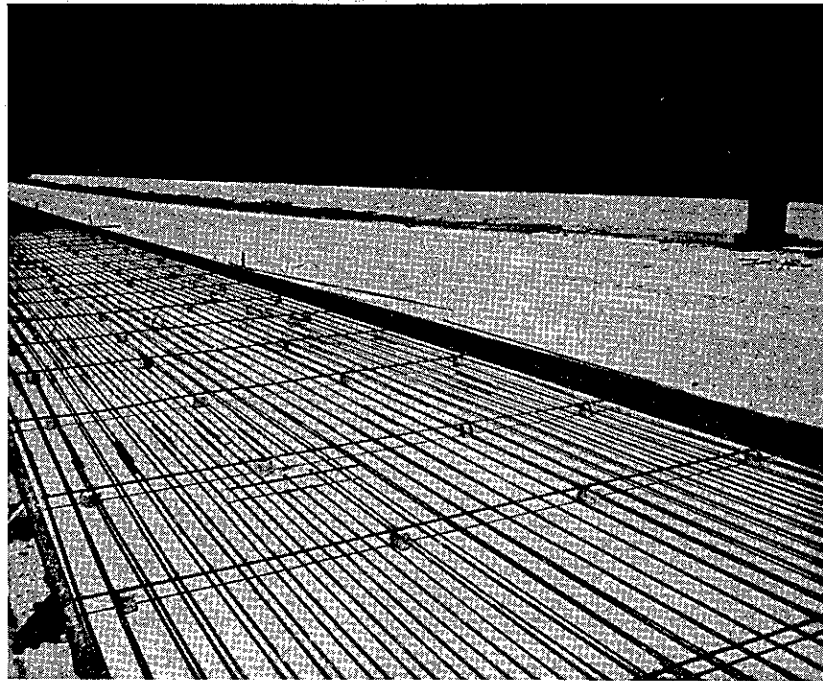
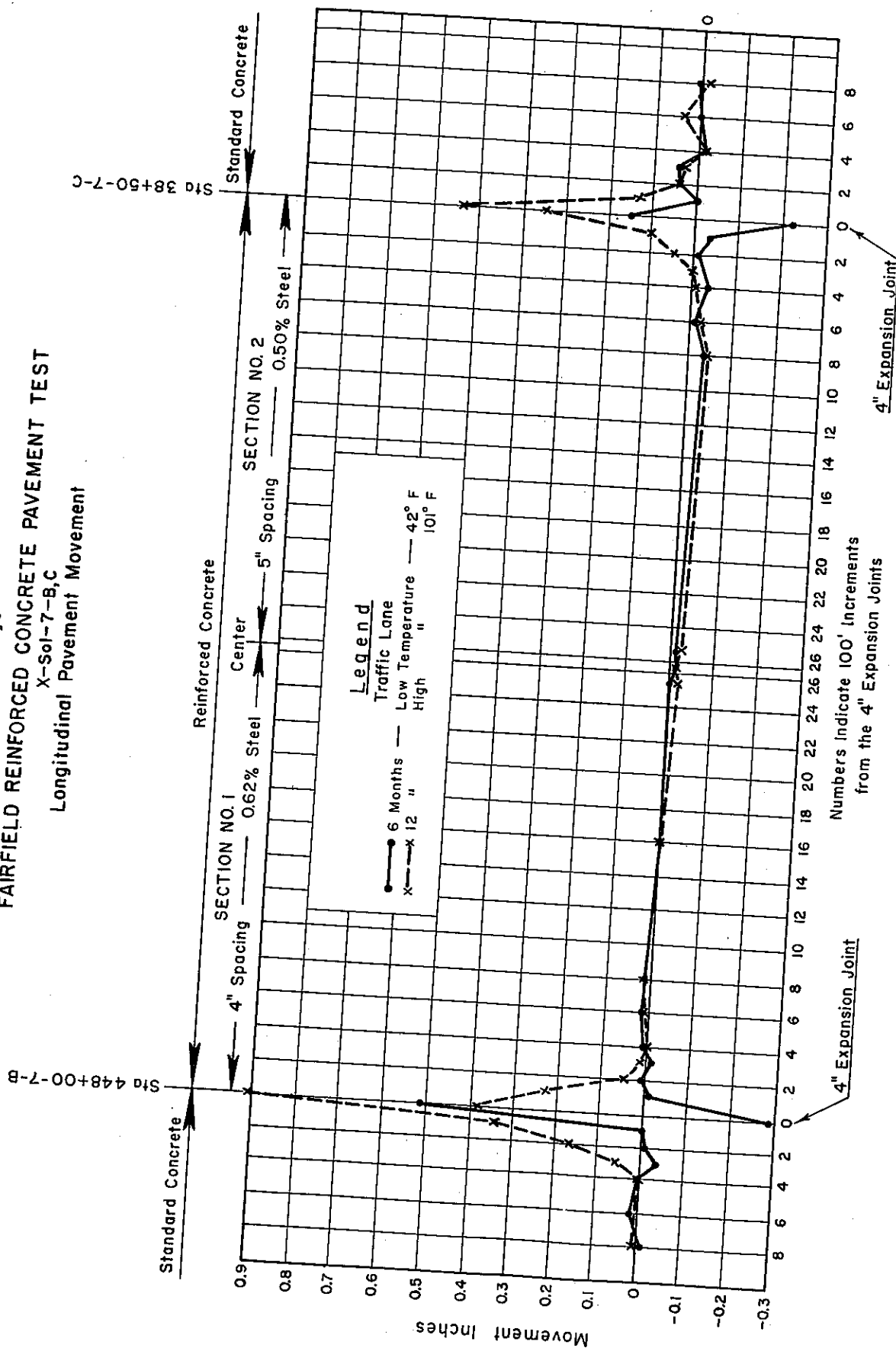


Fig. 4 Reinforcing Steel in place on base

Fig 5
FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST
 X-Sol-7-B,C
 Longitudinal Pavement Movement





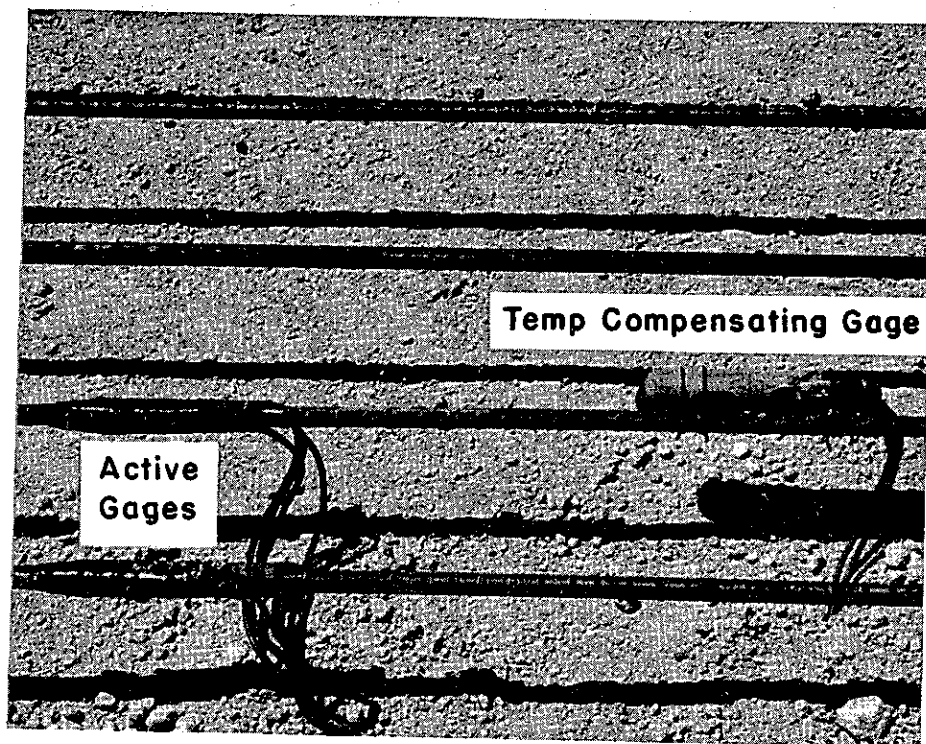


Fig. 6 SR₄ gages on reinforcing steel



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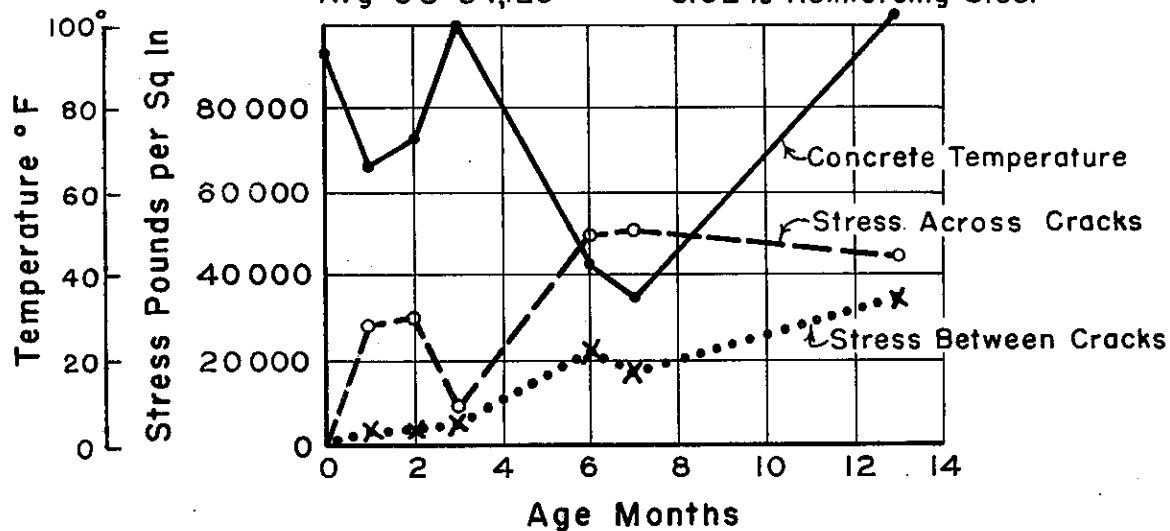


Fig 7

FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST
X-Sol-7-B,C
Average Stress in Reinforcing Steel

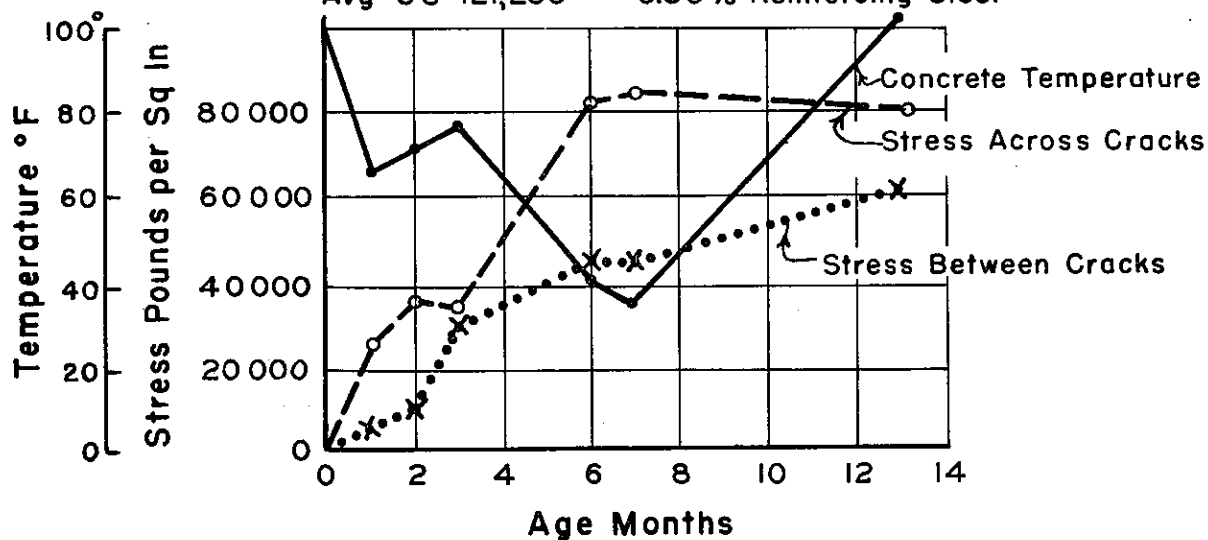
Section No. 1

Judson Pacific Murphy Reinforcing Steel
 Avg EL 54090 4" Steel Spacing
 Avg US 84,120 0.62% Reinforcing Steel



Section No. 2

Columbia Reinforcing Steel
 Avg EL 71,935 5" Steel Spacing
 Avg US 121,250 0.50% Reinforcing Steel



8500

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Plan of Placement of SR-4 Gages on Reinforcing Steel and Crack Formation

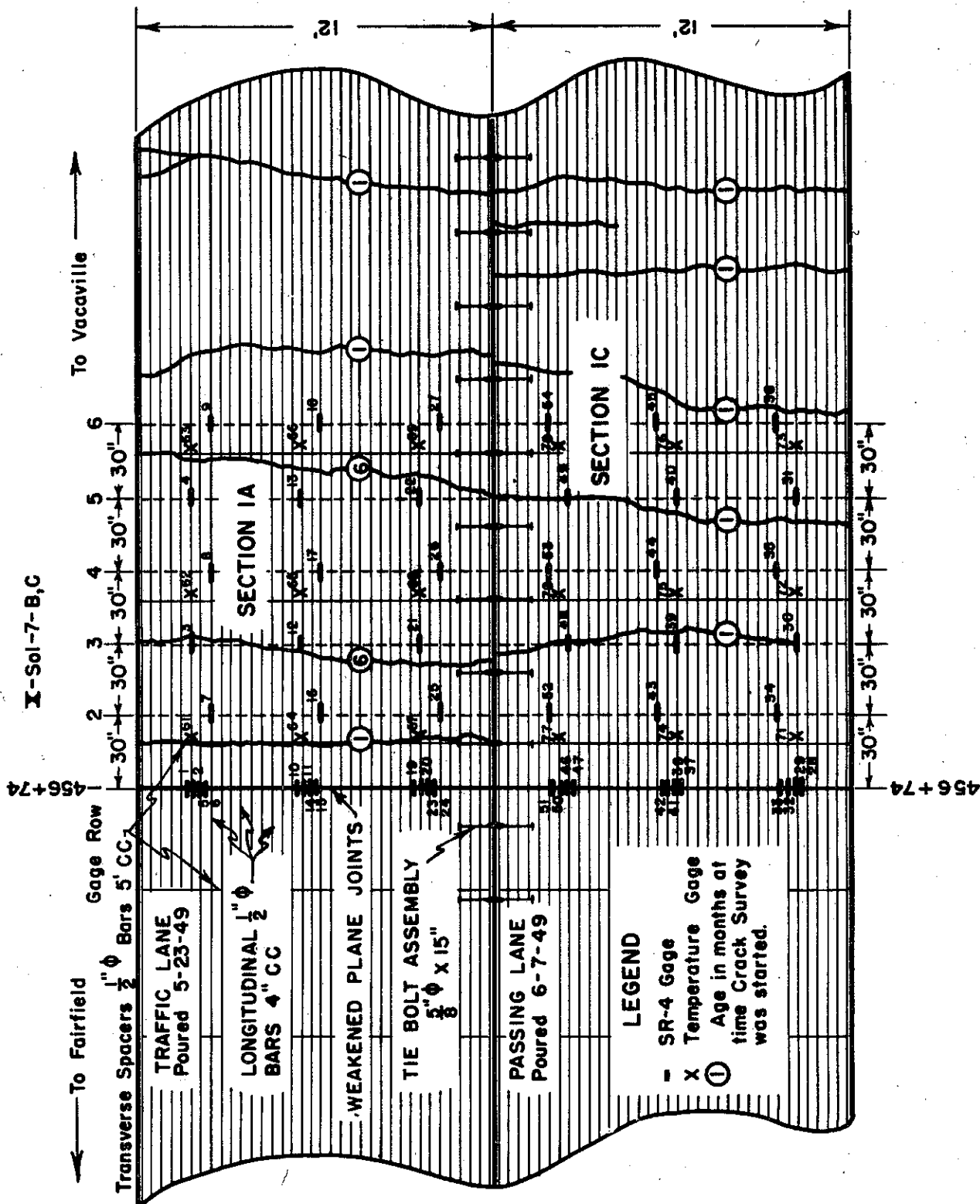
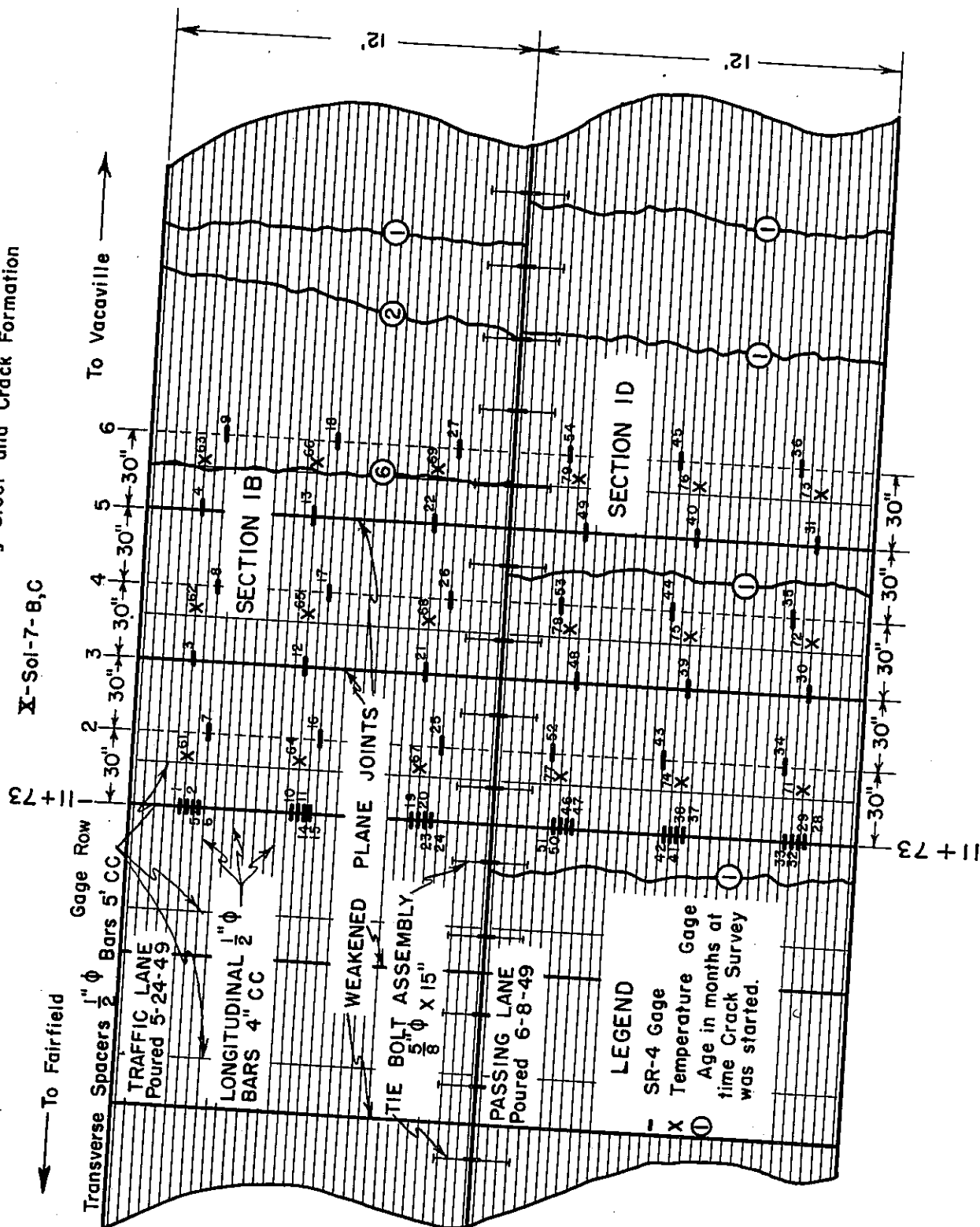


Fig 9



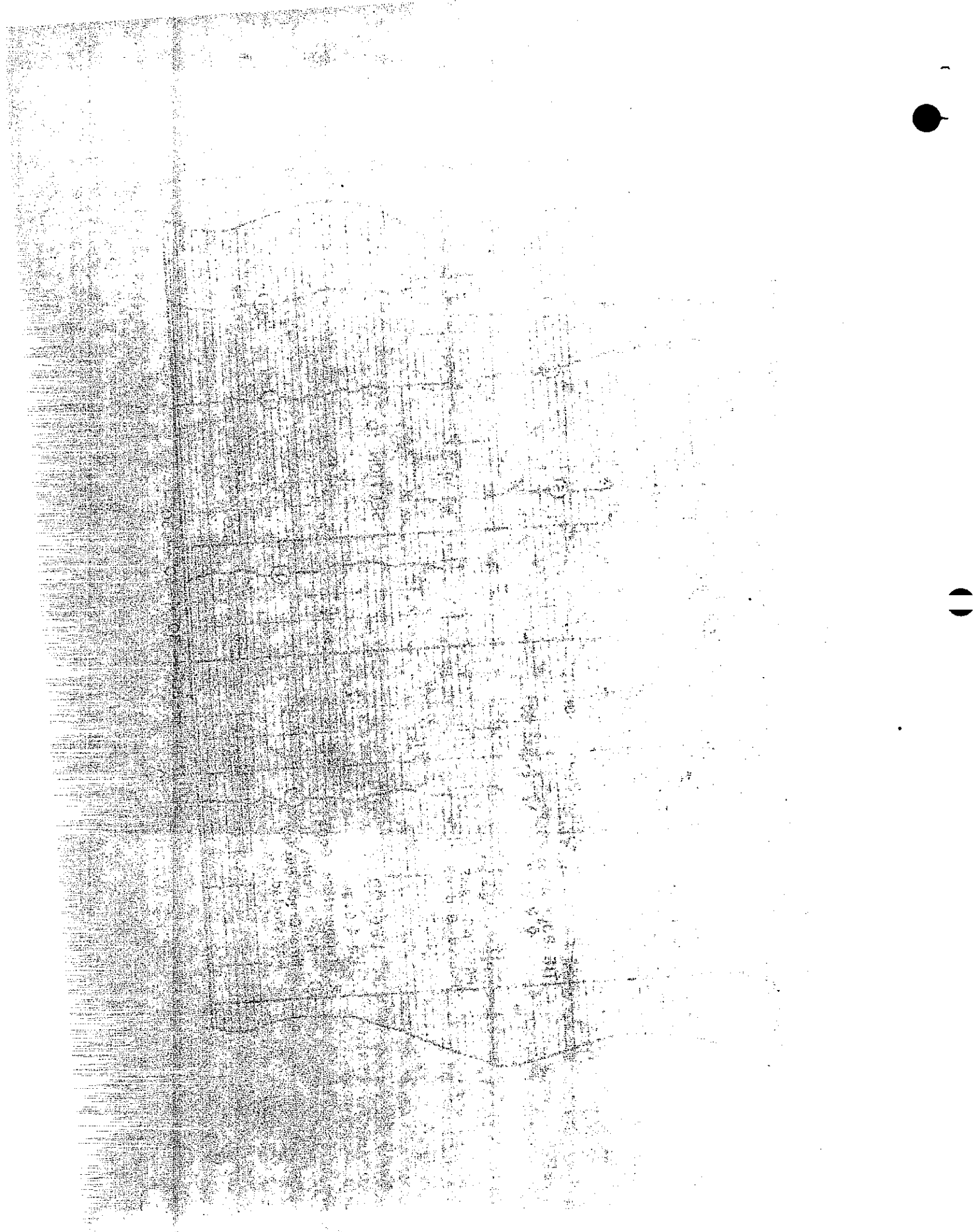
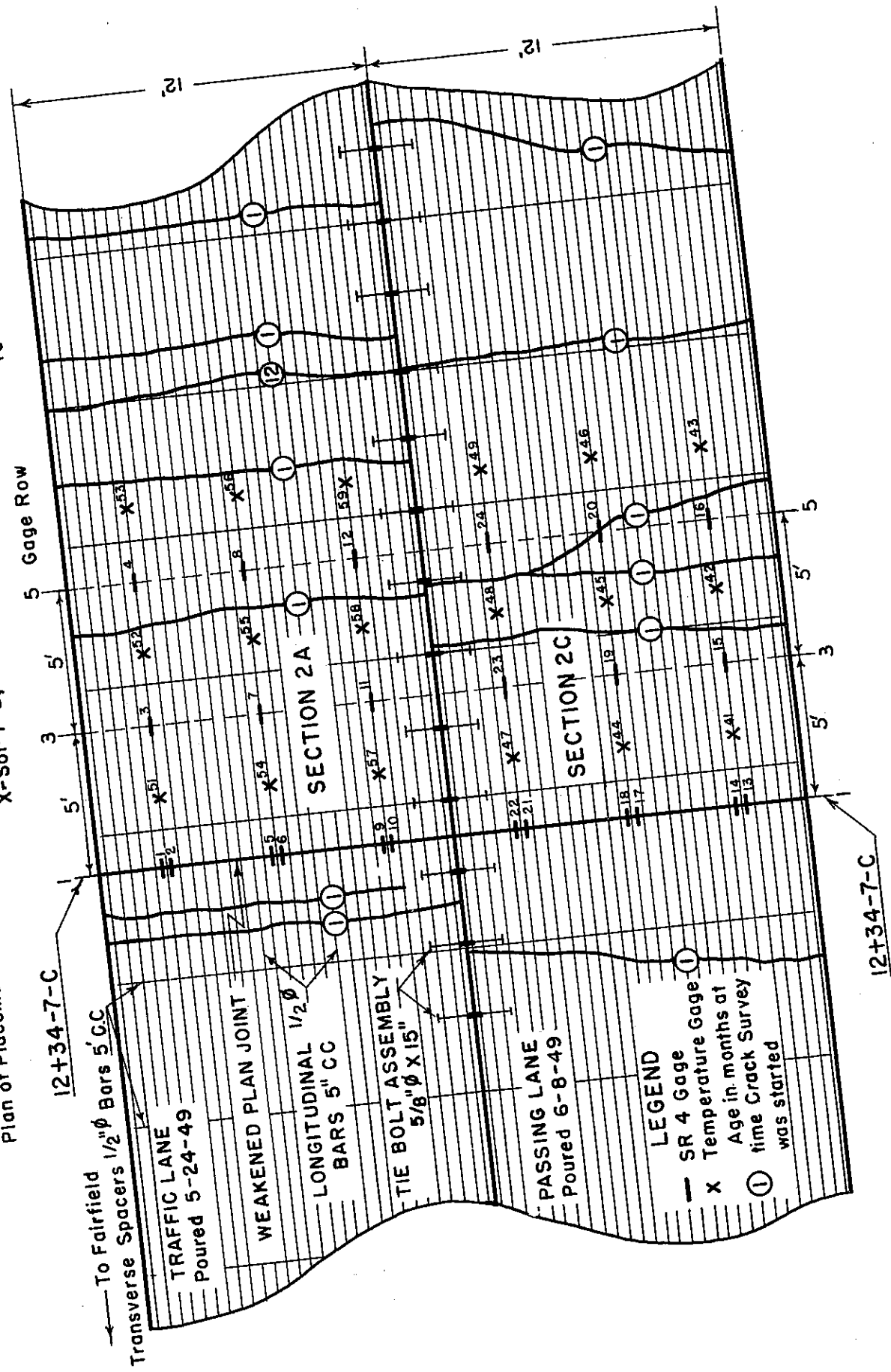
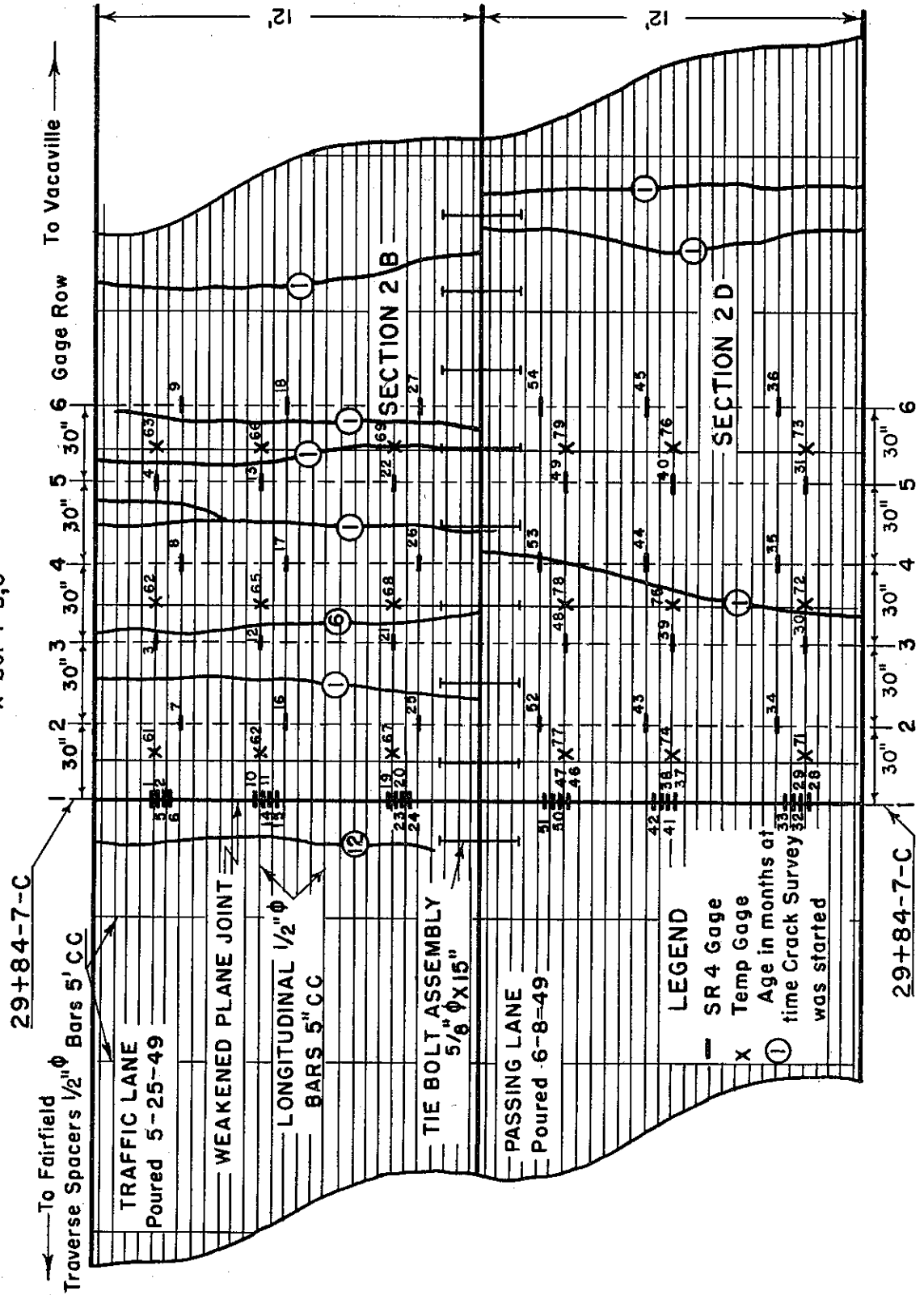


Fig 10
 FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST
 Plan of Placement of SR-4 Gages on Reinforcing Steel and Crack Formation
 X-Sol-7-B,C



FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST
Plan of Placement of SR-4 Gages on Reinforcing Steel and Crack Formation
X-Sol-7-B,C



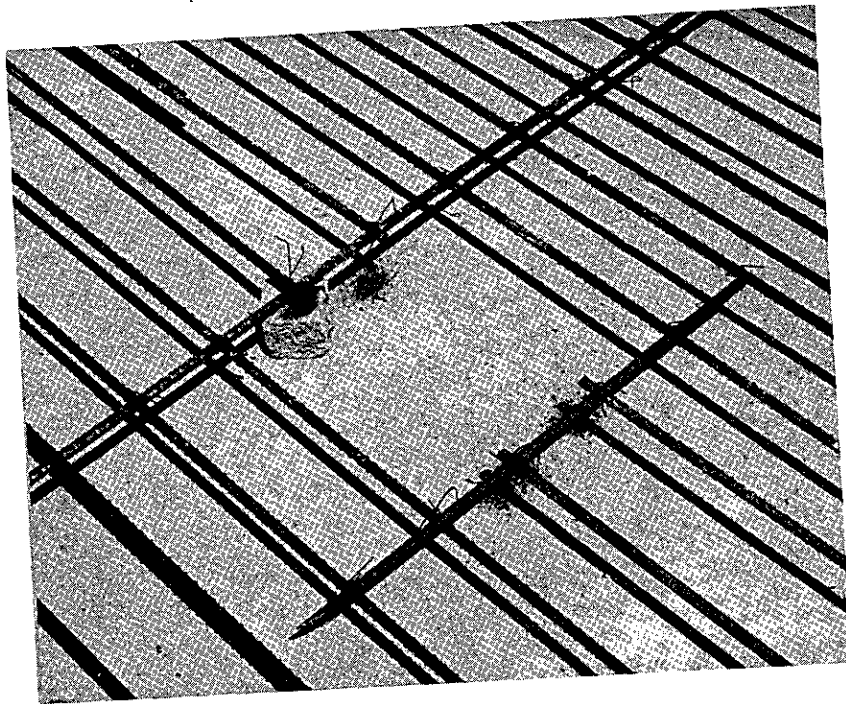


Fig. 12 Open space left in reinforcing
steel for cutting core

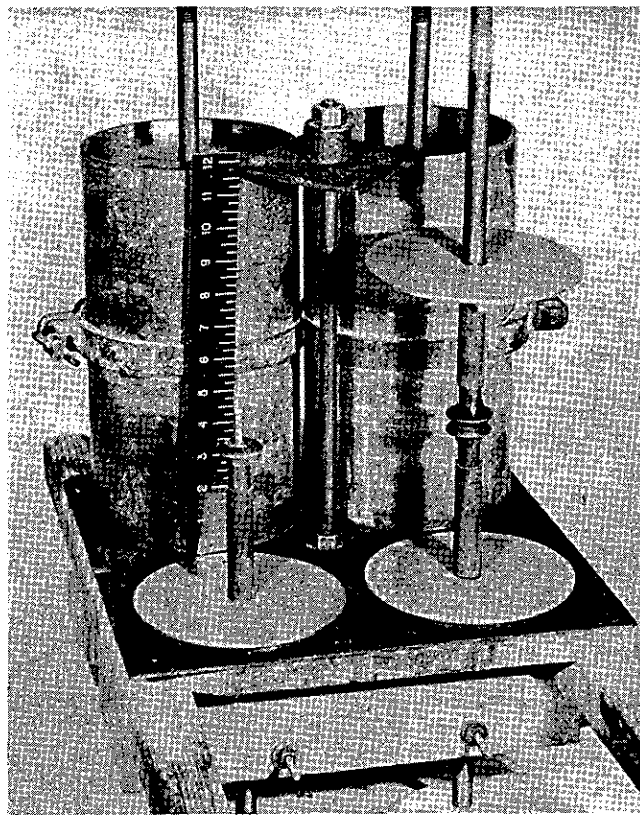


Fig. 13 Molds for making tensile strength test specimens

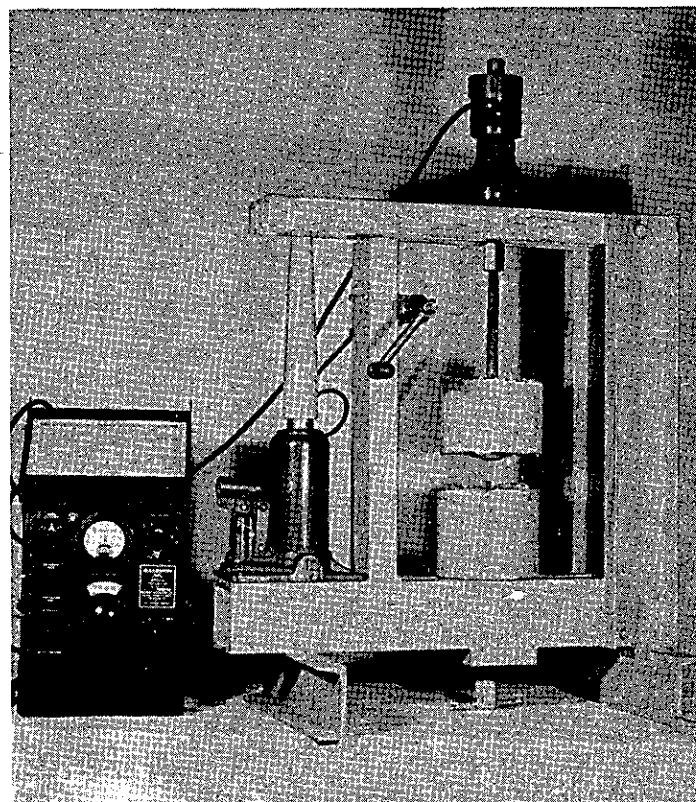
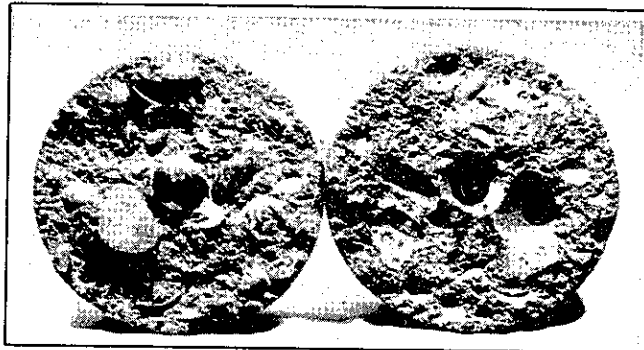


Fig. 14 Field equipment for breaking tensile strength test specimens

FRACTURES OF TENSILE TEST SPECIMENS

STANDARD CONCRETE

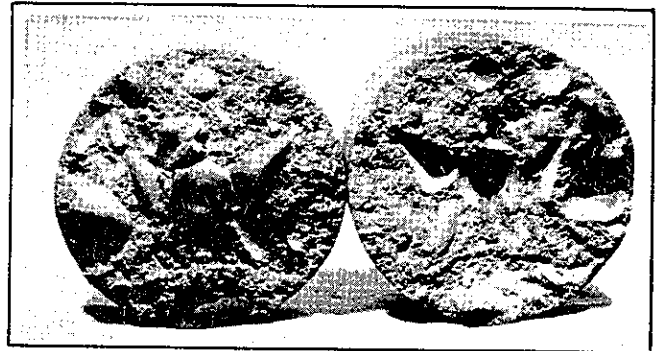
AGE 12 HOURS



TOP

BOTTOM

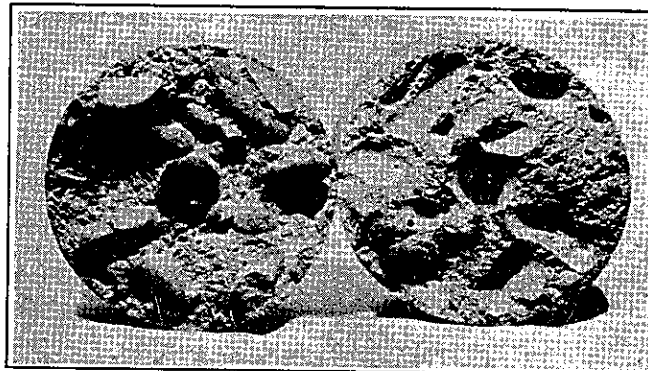
AGE 24 HOURS



TOP

BOTTOM

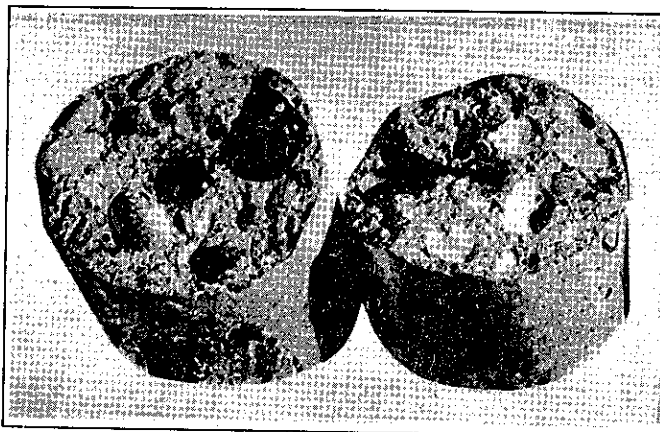
AGE 48 HOURS



TOP

BOTTOM

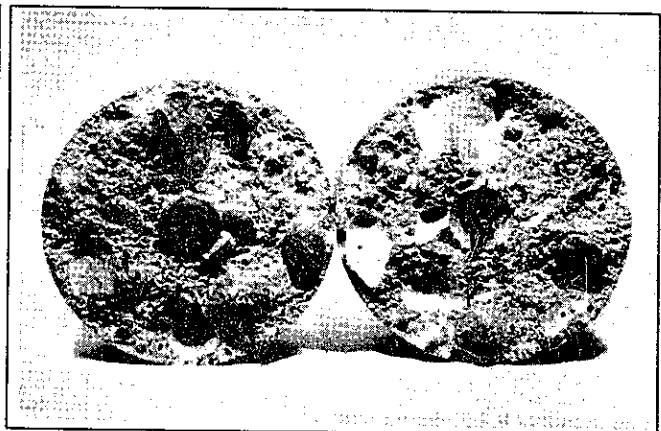
AGE 10 DAYS



TOP

BOTTOM

AGE 28 DAYS



TOP

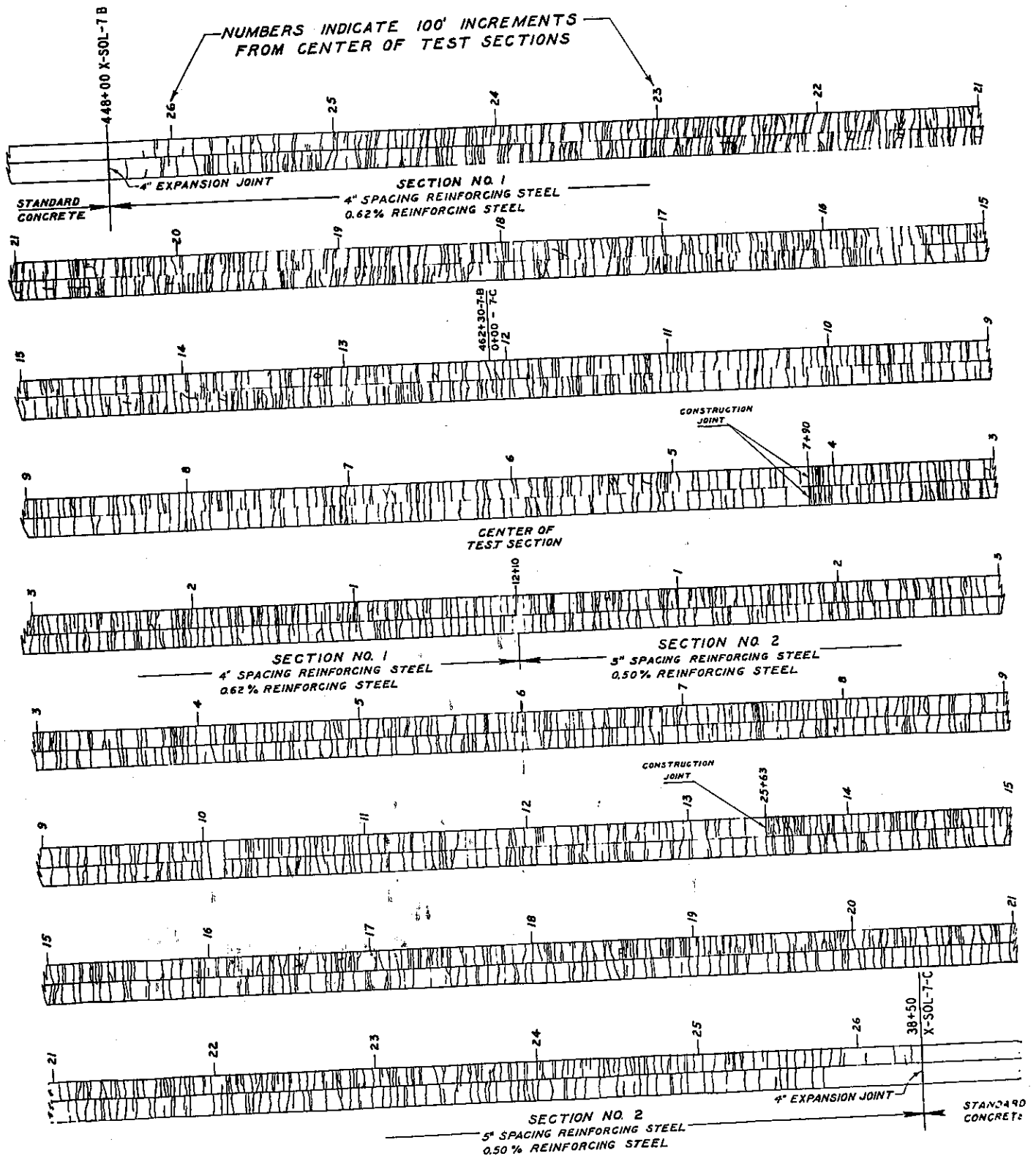
BOTTOM

Fig 15

Fig 16 FAIRFIELD REINFORCED CONCRETE PAVEMENT TESTS

X-SOL-7-B,C

CRACK FORMATION DURING FIRST YEAR



CONCRETE PAVEMENT TESTS

1. Slab Thickness	15.00 in.
2. Slab Length	12.00 in.
3. Slab Width	12.00 in.
4. Slab Area	144.00 sq. ft.
5. Slab Volume	216.00 cu. ft.
6. Slab Weight	10800.00 lbs.
7. Slab Density	150.00 pcf
8. Slab Strength	4000 psi
9. Slab Modulus	4,000,000 psi
10. Slab Deflection	0.01 in.
11. Slab Cracking	None
12. Slab Spalling	None
13. Slab Surface Finish	Good
14. Slab Joint Location	Center
15. Slab Joint Type	Expansion
16. Slab Joint Sealant	Bituminous
17. Slab Joint Width	0.50 in.
18. Slab Joint Depth	1.00 in.
19. Slab Joint Spacing	12.00 ft.
20. Slab Joint Alignment	Good
21. Slab Joint Condition	Good
22. Slab Joint Sealant Condition	Good
23. Slab Joint Sealant Application	Good
24. Slab Joint Sealant Cure	Good
25. Slab Joint Sealant Adhesion	Good
26. Slab Joint Sealant Flexibility	Good
27. Slab Joint Sealant Durability	Good
28. Slab Joint Sealant Resistance	Good
29. Slab Joint Sealant Compatibility	Good
30. Slab Joint Sealant Performance	Good

Fig 17

Res 00238

FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST

X-Sol-7-B,C

Average Slab Lengths

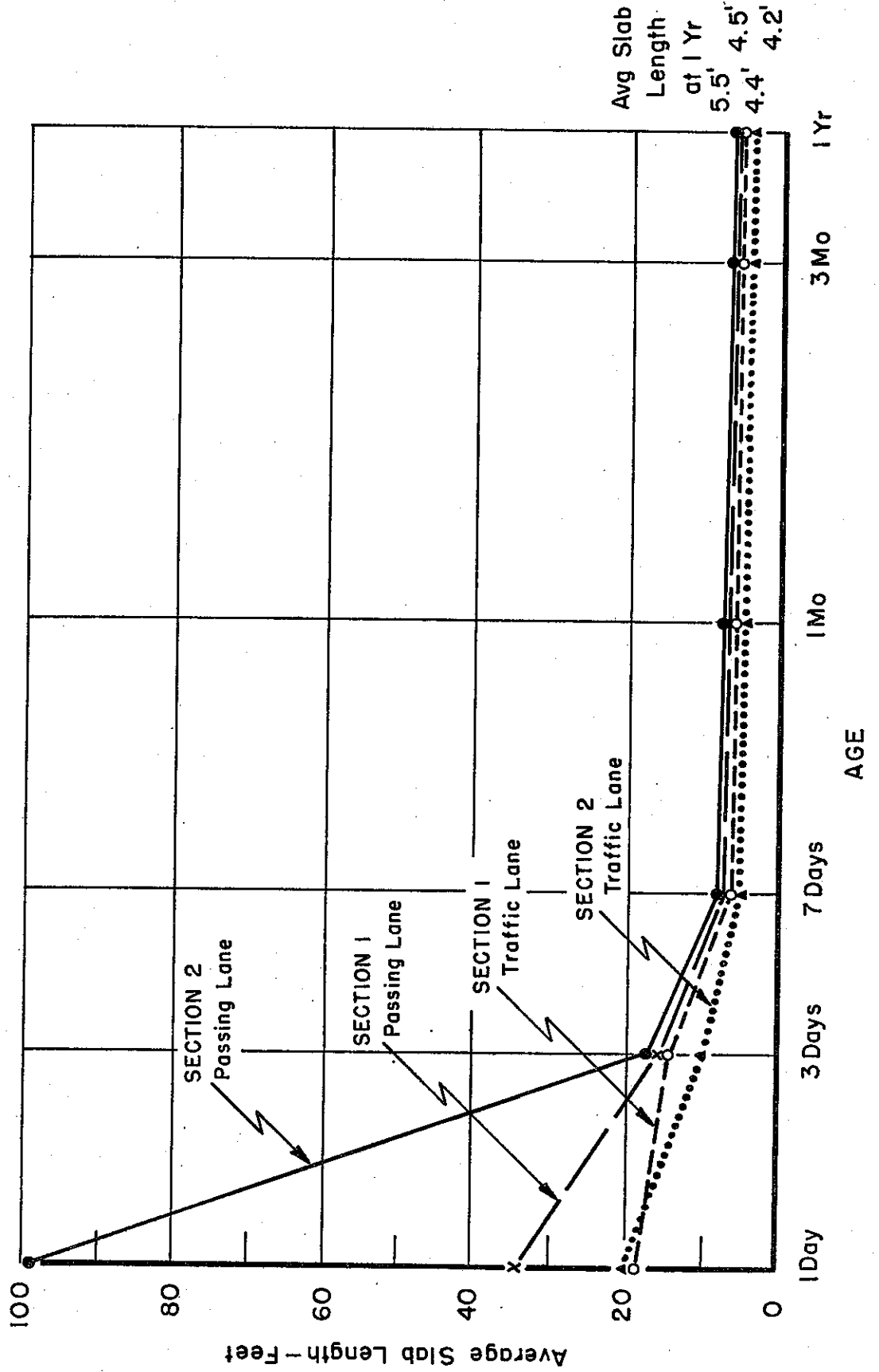


Fig 18

FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST

X-Sol-7-B,C

Average Slab Length and Number of Cracks Formed per 100' at Age of 1 Year

Section #2

0.62% Steel 4" Spacing

0.5% Steel 5" Spacing

CRACKS PER 100 FT.

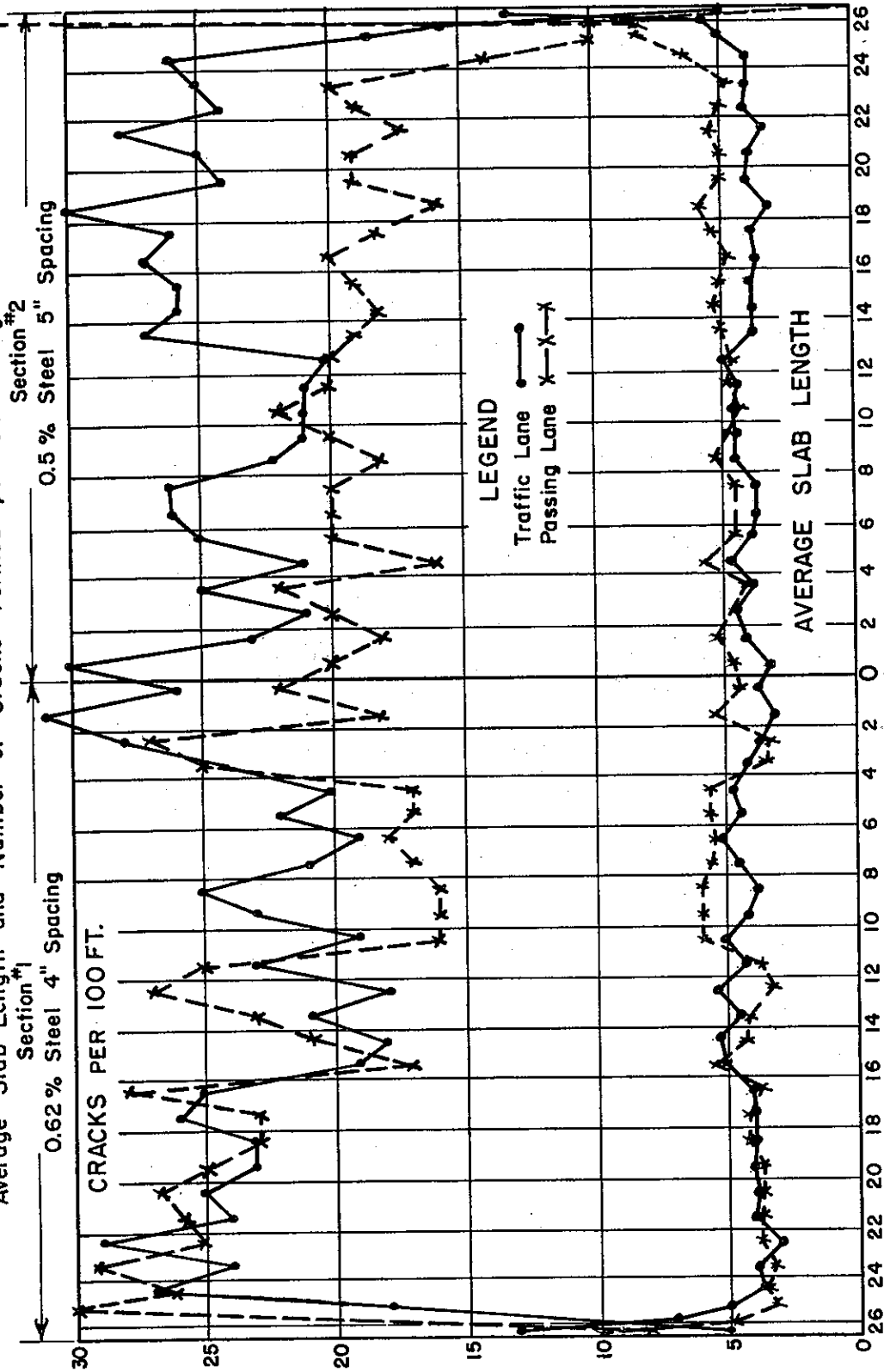
Average Slab Length Ft.—Number of Cracks per 100'

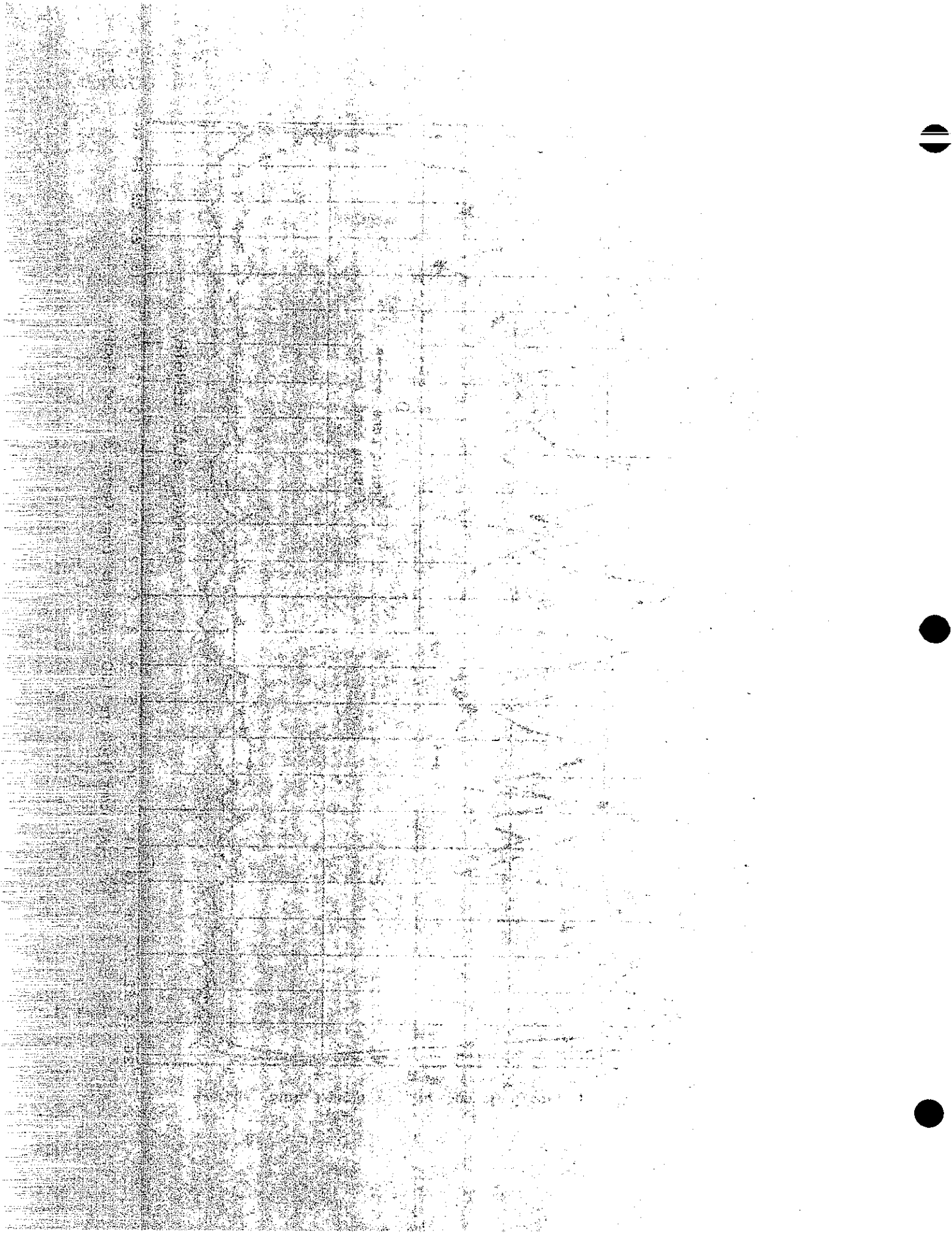
LEGEND

Traffic Lane —●—
Passing Lane —x—x

AVERAGE SLAB LENGTH

Numbers Indicate 100' Increments from Center of Test Section







(a) At Station 7+90

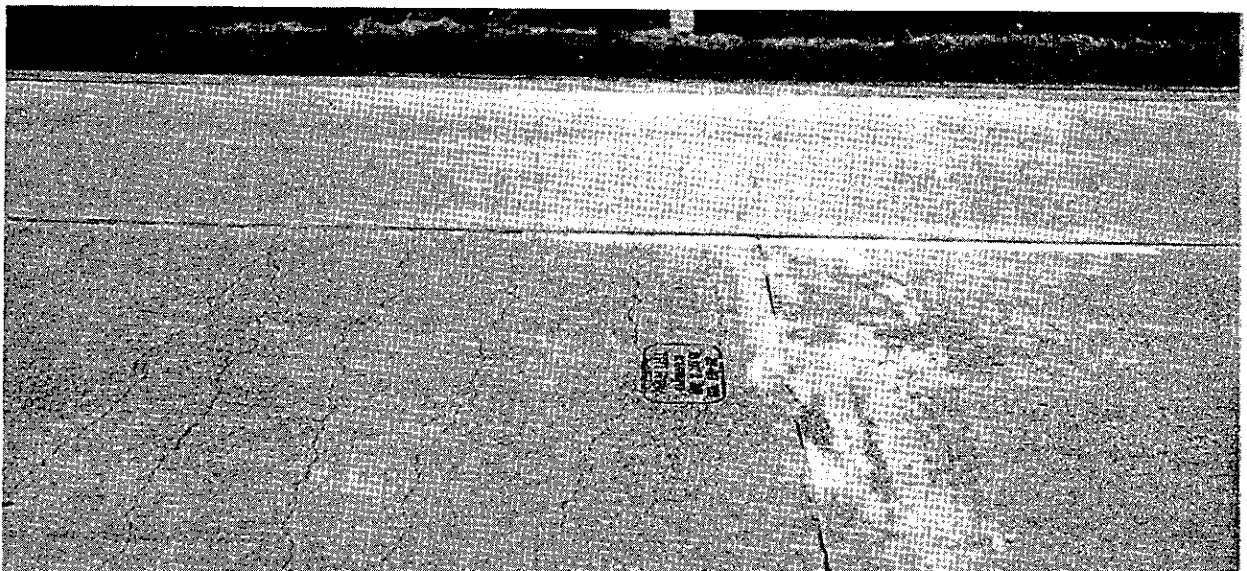
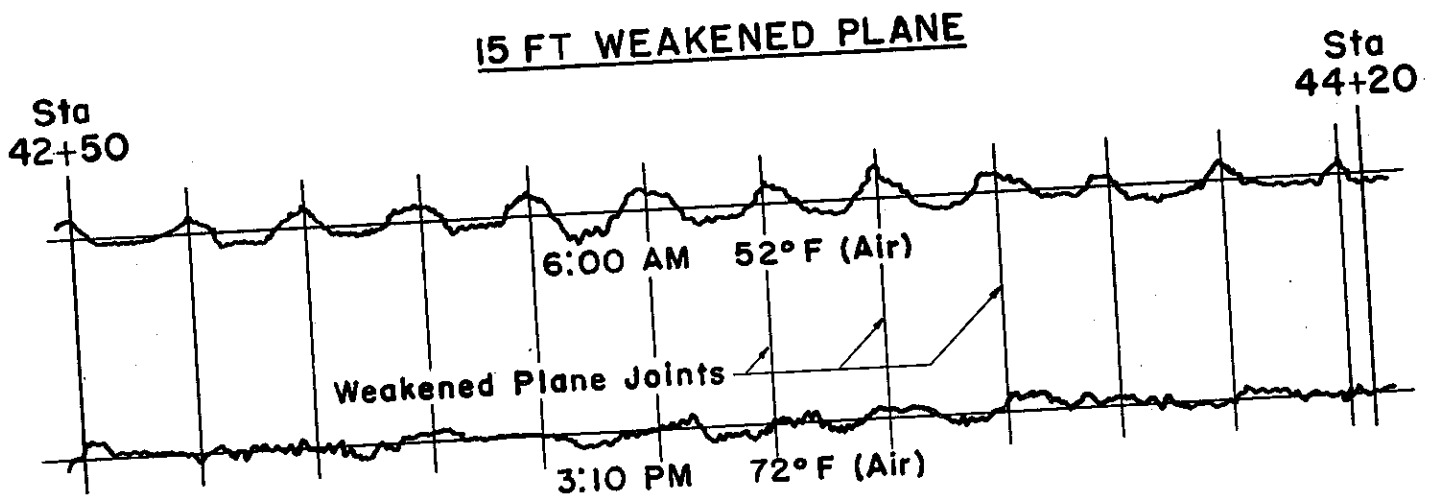
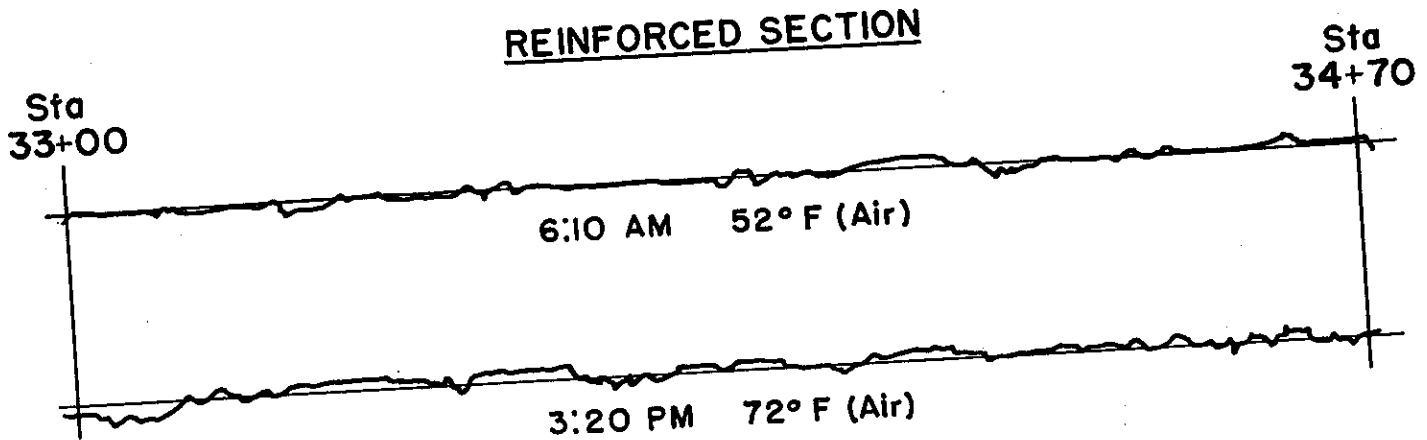


Fig 20

PROFILOGRAPH RECORDS
FAIRFIELD REINFORCED CONCRETE PAVEMENT TEST
X-Sol-7-B, C



SCALE
HORIZONTAL 1" = 25'
VERTICAL 1" = 1/2"

Profiles recorded on Profilograph approximately 350 feet north and south of 4 inch expansion joint at south end of reinforced section, station 38+50. These profiles were taken June 15, 1950.

RESEARCH No 00238
50-161-2

RECORDS CONTROL TEST

REINFORCED SECTION

(1A) REINFORCED

(1B) REINFORCED

(1C) REINFORCED

(1D) REINFORCED

(1E) REINFORCED

(1F) REINFORCED

REINFORCED SECTION

REINFORCED SECTION